BRAIN.

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THE WORK OF SIR CHARLES BELL IN RELATION TO MODERN NEUROLOGY.[1]

BY H. CAMPBELL THOMSON, M.D.

DISCOVERIES may be looked upon as incidents which occur from time to time in the course of the evolution of knowledge. Occasionally unexpected, rarely accidental, they are for the most part founded on the application of principles which have not only occupied the lifelong attention of the discoverer, but also that of many generations before him.

It is, nevertheless, generally through some particular discovery with which their names have become associated, that men of science are most often remembered, while the links which their work has forged in the chain of general knowledge are apt to be overlooked. To this rule Sir Charles Bell forms no exception, and while fully appreciating the magnitude of his discoveries—especially those concerning the spinal roots (the importance of which has been compared to Harvey's discovery of the circulation)—it is rather of the principles underlying the discoveries that I wish to speak this evening; my endeavour being to show that the more prominent of these principles were not only the natural sequence of those practised in previous times, but that—adorned with the additional knowledge Bell was able to supply—they were, in their turn, handed down for the use of those who came after. For the idea of dealing with the subject in this manner I must acknowledge my indebtedness to a perusal of the Harveian Oration for 1896, wherein the late Dr. J. F. Payne, with his unrivalled knowledge of the history of medicine, showed how profoundly results of the present always depend upon work of the past, as he illustrated by the manner in which

[1] Presidential Address of the Section of Neurology of the Royal Society of Medicine, October, 1925.

Harvey himself was influenced by the labour of generations that had gone before him.

Bell, who came to London from Scotland in 1804, was devoted to the study of anatomy, which in his opinion "surpassed all other studies in interest and usefulness," but in pursuing this science he also became a physiologist, for, not satisfied with observing the relationship of structures, he inquired also into their meanings, and it was in the study of function in relation to structure that much of the inspiration and greatness of his work lay. That the efforts he made in this direction have been generally recognized is shown by the remarks of Sir Charles Sherrington, who writes: "Progress of knowledge in regard to the nervous system has been indissolubly linked with determination of localization of function in it. This has been so from the time of the Bell-Magendie discovery of the difference of function in the two spinal roots, and Flourens' delimitation of the respiratory centre in the bulb."

In 1807 Bell had already begun to think seriously about the nervous system, for in a letter to his brother, dated December 7 of that year, he writes: "My new anatomy of the brain is a thing that occupies my head almost entirely," and a little later he says: "I consider the organs of the senses as forming a distinct class from the others." This last sentence deserves special attention since it seems to denote the basic idea from which further steps in the doctrine of the specificity of nerves were evolved. The gradual development of this idea can be traced through his writings, when, for example, he says, "Every nerve of the sense is limited in its exercise and can minister to certain perceptions only," a statement which he amplifies later when he writes, "Whatever may be the nature of the impulse communicated to a nerve, pressure, vibration, heat, electricity, the perception in the mind will have reference to the organ exercised, not to the impression made upon it. Fire will not give the sensation of heat to any nerve but that appropriated to the surface. However delicate the retina, it does not feel like the skin. The tongue enjoys two senses, touch and taste, and by selecting the extremity of a particular nerve or, what is the same thing, a particular papilla, we can exercise either the one or the other separately." Following out this line of thought he proceeded to test his beliefs in the following order:—

(1) He examined the spinal nerves and observed their exact resemblance to one another.

(2) He proved by experiment that their roots had different

functions, and that they really were what their anatomy indicated, double nerves.

(3) He examined nerves of the encephalon and found the fifth the only one which, from having two roots, could bestow upon the head those double functions of sensation and motion which were given to the body through spinal nerves.

(4) He selected the nerves of the face for experiment in order to demonstrate to others what he had by anatomy convinced himself to be their function.

The date of his first experiments on the spinal roots—a point of some importance in view of subsequent controversy—is fixed by a letter of March 12, 1810; while in another letter of December 6, 1814, he mentions experiments with the galvanic current, "to try how far the actions of nerves and muscles will agree with the divisions of nerves I have made by dissection," and goes on to say: "Now you know what I hope to prove is that there are two great classes of nerves distinguishable in function, the one sensible and the other insensible."

To strengthen his conclusions derived from examination of the spinal nerves he next proceeded to the cranial nerves, and by experiments on an ass he was able to show a difference in function—hitherto unrecognized—between the fifth and seventh nerves, and though he erred in some of his conclusions—to which allusion will be made later on—he opened up the path which enabled others to supplement the work he had begun.

Another ingenious piece of work was the formulation of his "Respiratory System of Nerves," the idea of which again arose from anatomical considerations in relation to nerve distribution. Though his hypothesis of the arrangement of nerves on this basis into two great divisions, regular and irregular, did not stand the test of time, it served its purpose of drawing attention to the importance of muscular movements in respiration, for until that time the mechanism of respiration gave rise to no other idea in the mind of the physiologist than of certain chemical changes wrought in the lungs.

In estimating the importance of the initiation of these lines of work, it must not be forgotten that physiology of the nervous system was at this period almost an unknown quantity, and that, as will be shown later, there was a gap in this branch of knowledge extending as far back as the time of Galen, whose work Bell may be considered to have largely resuscitated as a starting point of his own.

In what little esteem the possibilities of physiology were held in

those days is shown by the attitude of a then eminent Fellow of the Royal Society, who, having always limited his views on the mechanism of respiration to chemical processes, quite lost patience when he heard of the idea of respiratory nerves to the face; while the general apathy of the times towards anatomy was equally reflected in the statement of another learned Fellow who said to Bell, "In your department (i.e., anatomy) we can hope for nothing new; after so many eminent men in successive ages have laboured on your subject no future discovery can be expected."

Such was the atmosphere of veiled antagonism into which Bell introduced his views and arrived at conclusions which, in the words of one of his contemporaries, "led to the entire remodelling of nervous physiology."

In addition to Bell's genius for making discoveries by piecing together knowledge which had, so to speak, become ripe for the occasion, his writings reveal numerous suggestions and ideas which, though in advance of his own time, have in many instances since been further developed and incorporated in the texture of present-day knowledge.

As one instance we may take his observations on the failure of a hemiplegic to raise the shoulder voluntarily, in contrast with the movement associated with respiration; an observation from which he concluded that a "strictly voluntary act of respiration is performed through the common class of voluntary nerves, and that when the chest is raised in an act of respiration movement is effected through those nerves which control the muscles in respiration." He thus virtually recognizes the difference between the bilateral action of certain muscles for involuntary movements and unilateral action for voluntary movements, as later was particularized in the upper part of the trapezius by Hughlings Jackson, and in the latissimus dorsi by C. E. Beevor, though, as in other places, owing to absence of knowledge concerning the brain, he attributes functions to the peripheral system instead of referring them to higher levels.

Another conclusion, since extensively developed, was that concerning the existence of "muscle sense." After confirming previous observations of Meckel and Monro regarding the distribution of sensory nerves to muscles, Bell asks himself "whether it be necessary to the governance of the muscular frame that there shall be a consciousness of the state or degree of action of muscles," a question which, after reviewing evidences from different sources, he answers in the affirmative, and finally concludes that "between the brain and the muscles there is

a circle of nerves; one nerve conveys the influence from the brain to the muscle, another gives the sense of the condition of the muscle to the brain."

That Bell also recognized the existence of different levels of function is indicated by the remarks he makes in relation to his attempts to classify the nerves of the face, mouth, throat and neck. He says: "The principle which is to guide us is obtained by ascertaining what parts of the organization of an animal are necessary to life and motion; what organs are superadded as the animal advances in the scale of existence, and are necessary to higher and more complex engagements and actions. In the human body there is the same uniform and symmetrical system of nerves as in the leech or worm, although it is obscured by a variety of superadded nerves. These superadded nerves belong to organs which in tracing the orders of animals upwards are observed to accumulate gradually until we arrive at the complication of the human frame.

"These nerves, additional and superadded to the original system, do not destroy, but only obscure that system, and accordingly, when we separate certain nerves, the original simple system is presented even in the human body."

The statement that, "these nerves, additional and superadded to the original system, *do not destroy but only obscure that system*" seems to foreshadow that important principle, laid down some fifty years later by Hughlings Jackson, stating that destructive lesions produce negative conditions which permit positive symptoms to appear—a principle which has been so ably elaborated by Henry Head and others of the present day.

In this respect it is of interest to note that although Bell was a staunch believer in the special creation of man, he realized from geological evidence that man did not exist from the earliest times. He considered that living creatures had been created successively as the nature of the earth became suitable for their existence. In expressing this view he is careful to avoid entanglement in any evolutionary idea, for he goes on to say: "When we acknowledge that animals have been created in succession and with an increasing complexity of parts, we are not to be understood as admitting that there is here proof of a growing maturity of powers or an increasing effort in the Creator. . . . We thus mark changes in the earth's surface and observe, at the same time, corresponding changes in the animal creation. We remark varieties in the outward form, size and general condition of animals, and corresponding varieties

in the internal organization—until we find Man created, of prominence over all, and placed suitably in a bounteous condition of the earth."

Other instances of similar nature might be given of Bell's prescience, but it will suffice to mention one more, which in the light of later events is perhaps the most interesting of all, the idea of reciprocal innervation of muscles. Bell observed that if he appended a weight to a tendon of an extensor muscle which gently stretched it, the contraction of the opponent flexor was attended with a descent of the weight, thus indicating relaxation of the extensor, from which he concluded that, " if such relationship be established through the distribution of the nerves between the muscles of the eyelids and the superior oblique muscles of the eyeball, the one will relax while the other contracts." On this conclusion Sir Charles Sherrington remarks that, like Descartes, Bell pictured a peripheral inhibition, and that these two (i.e., Descartes and Bell) " with remarkable prescience examined the existence of an action of nerve on muscle just such as was later discovered by the Webers in the vagal inhibition of the heart, an inhibition which Volkmann, previous to the Webers, met in the course of experiment, but, unexpectant of it, rejected as illusory and due to some experimental error."

Perhaps nowhere is Bell's breadth of thought, in relation to the times in which he lived, better illustrated than in his concluding remarks of the chapter from which the sentences dealing with the creation of man have already been quoted, where he says: " The heavenly bodies, in their motions through space, are held in their orbits by the continuance of a power not more wonderful or more deserving of admiration than that by which a globule of blood is suspended in the mass of fluids—or by which, in due season, it is attracted and resolved. . . ." An interesting analogy to have made in the light of the modern conception of an atom as a miniature solar system.

It is frequently the fate of great men to be praised extravagantly at one time and to be disparaged at another, and were it not for a criticism in 1911 which tended to belittle the value of his work, the controversies of his lifetime as regards priority of certain experiments and conclusions might well have been considered buried.

It is obviously difficult to form any independent opinion on the interrelations of workers of a hundred years ago, for so much turns on unwritten information that was available at the time, and even written words of so long ago did not always convey the identical meanings attached to them to-day. When, therefore, we come to apportion credit between Bell, Magendie and Mayo, the last of whom was a colleague of

Bell's on the staff of the Middlesex Hospital and did much to advance the physiology of the nervous system, around whom the controversies mainly turned, it seems to me we cannot do better than follow a Report on the Physiology of the Nervous System delivered by Dr. William Charles Henry at the meeting of the British Association in 1833. At that date the individuals principally concerned were still alive, and it is reasonable to assume that the lecturer was conversant with the general opinions of the times, the perspective of which his scientific education would enable him to judge.

In speaking of the then recently acquired knowledge of in-going and out-going impulses of the nervous system, Dr. Henry says: "The honour of this discovery, doubtless the most important accession to physiological knowledge since the time of Harvey, belongs exclusively to Sir Charles Bell. . . . His successive experiments on function, guided always by strong anatomical analogies in structure, in origin or in distribution, have led to the entire remodelling of physiology. Much light too has been thrown on the functions of the encephalic nerves, and especially of those supplying the face and its connected cavities by Mr. Herbert Mayo, who has analysed their anatomical position and pursued their course with singular precision, and has thus been enabled to correct some errors in detail in the system of Sir Charles Bell."

This last passage refers to Mayo's correction of the error Bell made in thinking that the fifth nerve and its branches were endowed throughout with the attributes of motion and sensation; a mistake founded on the inability of an ass to pick up its food from loss of sensation in the lips, and not to loss of motion as Bell for a time was led to believe.

With reference to Magendie, Dr. Henry says, "Magendie has described the following experiments (i.e., experiments on spinal roots), which he has since declared were made without any knowledge of the prior ones of Sir Charles Bell." These remarks made in 1833, in which credit is thus given to the different investigators, would seem to be a fair summary of the position.

Nor can the magnitude of Bell's discovery be decried if he did not completely round off all there was ever to be known about the anterior and posterior roots, as some would seem to have thought.

The basic fact he discovered was that the two roots possess different functions, and upon this depended the possibility of further research. By such research Bell next definitely established the motor functions of the anterior roots, while for a time, owing to experimental difficulties

concerned with testing sensation, he was less dogmatic about the sensory functions of the posterior roots.

There is, moreover, in the chronicles of those times no secret made of the fact that Bell had some difficulty in deciding the precise parts the posterior roots played in the conduction of sensation, for in giving a summary of the root experiments in a paper, "Partial Paralysis" John Shaw—a brother-in-law of Bell—says, "It was easily shown that if only the posterior set was destroyed, the voluntary power over the muscles continued unimpaired; but the pain necessarily attendant upon the performance of the experiment prevented us from judging of the degree of sensibility remaining in the part." Further evidence of what Bell had in mind regarding posterior roots is also shown by his opposition to a prevailing idea of those times that ganglions were intended to cut off sensations.

That there were at times some acute differences of opinion with the French School is undeniable, but that these estrangements were not continuous is clear from various incidents, of which one is a letter of June 10, 1822, in which Bell says, "My discoveries have made more impression in France than here, and I have received a second message from Magendie saying that if I would send them any short account I should have the prize medal."

The fact that some of Bell's conclusions were incomplete, or failed in their entirety to stand the test of time, in no way detracts from the value of his work as a whole, or from the great impetus he admittedly gave to the furtherance of physiological research. Indeed, in work of this quality, even mistakes have their uses, for as Payne, in speaking of errors, has truly said, "Rather let us call them imperfect truths, for they are parts of a continuous evolution in which the so-called truth and the so-called error are inseparably mingled."

As regards his work and methods, Sir Charles Bell has been compared with Harvey, and he is undoubtedly entitled to a place in the direct line of famous men as assigned to him by Payne, who writes thus: "On the revival of anatomy, Vesalius and his contemporaries practised vivisection, closely imitated from Galen, but established nothing in nerve physiology, Harvey published nothing about the nervous system. Willis reconstituted the anatomy of the brain, but added little experimental with regard to its functions. It is not till we come to the days of Sir Charles Bell and Magendie that we find anyone comparable to Galen as a nerve physiologist." That Bell derived much of his inspiration from Galen seems clear from many references. There

is an interesting similarity in religious thought between Galen's physiological work "De Usu Partium" and Bell's book on the Hand, both of which were written to indicate the wisdom of the Creator, as shown in the adaptation of the parts of the body to their functions; Bell's view being that the hand "presents the last and best proof of that principle of adaptation which evinces design in the Creator."

Of Bell's merits as an artist you can judge from his paintings and other works of art which I am able to show you this evening. There was at the end of 1807 a possibility of Bell being elected Professor of Anatomy to the Royal Academy, but eventually it was decided that the holder of the appointment at that time should continue in office. That he was successful in applying his knowledge of anatomy, physiology, and art in the practice of his profession is shown, not only by his success in London, but also by the invitation he received in 1835 to occupy the chair of Surgery at the University of Edinburgh, the duties of which he left London to take up only a few months after he had been instrumental in founding the Medical School of the Middlesex Hospital, to which he had been elected surgeon in 1814.

As regards Bell's work on the nervous system, I hope the bare outline I have been able to put before you is sufficient to give some adequate idea of his breadth of thought and the position he attained in the history of Medicine—a position in which I venture to think he is to be accepted as a worthy successor of such famous names as Galen, Caius, Linacre and Harvey, and an inspiring predecessor of such makers of neurological history as Marshall Hall, Hughlings Jackson, and Victor Horsley, down to the many honoured names of those who are happily with us at the present day, the numbers of whom, past and present, form a long list which represents a continuous line of work of unsurpassed quality of which the British school of Neurology is justly proud.

THE MORPHOLOGY OF THE GASSERIAN GANGLION.[1]

BY CHARLES H. FRAZIER, M.D., ScD.

AND

EDWARD WHITEHEAD, M.D.

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Introduction by Charles H. Frazier.

Trigeminal neuralgia, by virtue of its frequency in the neuro-surgical clinic, commands attention. In the Neuro-Surgical Clinic of the University Hospital there have been, not including atypical forms, 971 cases of the major form of the disease, and the yearly number is increasing rather than decreasing. Though lacking many of the graver and more complicated features of brain tumour, which might be said to be our major problem, trigeminal neuralgia cannot yet be relegated to the side lines. There are many aspects of this disease still unexplained, and though relief may be afforded for a while by alcoholic injections, the radical operation, for various reasons, is demanded in a considerable number of cases. When the mortality of the major operation had been reduced to less than half of 1 per cent., and when other refinements had been introduced, we were wont to regard the technic as perfected. But chiefly because of the possibility of corneal complications following the radical operation, the frequency of which has been under—rather than over—estimated, we must admit of the treatment of trigeminal neuralgia that the last word has not been said. While the percentage of corneal complications developing before the patient is discharged from the hospital after operation may be small, the possibility of keratitis developing later and the precautions the patient must take for its prevention, attach an unquestionable stigma to the operative treatment.

Perhaps it would not be amiss here to outline briefly our experience with the radical operation for major trigeminal neuralgia. Section of the sensory root, as a deliberate substitute for resection of the ganglion of Gasser, was performed for the first time in the Neuro-Surgical Clinic of the University Hospital in 1901. Since that time the writer has

[1] Read before the American Neurological Association, Washington, D.C., May 5, 1925.

performed the operation 396 times. While the first operation was performed in 1901, this radical suggestion was made by Spiller in 1899, and in the meantime the feasibility of the operation and its certainty as a means of permanent relief were confirmed by the writer in the experimental laboratory.

During these twenty-five years (1901-1926) the operation has been accepted pretty much the world over as a substitute for gangliectomy, chiefly because it has so reduced the risks, hazards and fatalities. In these 396 operations performed by the writer there have been two deaths, a mortality-rate of 0·5 per cent.; in the last 210 there was but one death, 0·4 per cent.; and in the last 155 consecutive operations no deaths. Thus it may be said that the risk of operation has been reduced to practically an irreducible minimum.

During this quarter of a century the operation, as first practised, has undergone certain modifications. Prior to 1918 the motor root was always sacrificed. Why it never occurred to those concerned with this particular operation that the motor root could be easily recognized and conserved is difficult to explain. But from 1918 it has been our routine practice to separate the motor from the sensory root before the latter is sacrificed. Thus the innervation of the muscles of mastication is conserved and the cosmetic result is improved by preventing the temporal muscle atrophy.

The last modification of the operation, as told elsewhere, was the substitution of subtotal for total section of the sensory root.

As to the operation itself, it is always performed in the sitting posture, the incision is well within the hair line with a short horizontal extension along the upper margin of the zygoma; the foramen spinosum is plugged with cotton and the middle meningeal artery divided without ligation. With an illuminated retractor and a suction apparatus, the field of operation is at all times clearly exposed and without any difficulty the superior surface of the ganglion is uncovered, and later by an oblique incision in the ganglion sheath the ganglion itself and sensory root come into view. It remains then only to isolate the motor root and to divide all but the two inner fasciculi of the sensory root.

A year ago I presented to the American Neurological Association a preliminary report on subtotal resection of the sensory root. Covering a period of ten years this modification of the customary procedure was performed in twenty-five selected cases, and in not one had there been a keratitis after the patient was discharged from the hospital, nor was there a single case of recurrence of pain in any one of the three divisions of the trigeminal nerve.

While this preliminary clinical experience would seem to offer sufficient justification for the acceptance of subtotal root resection as a substitute for the prevailing total section, other supporting evidence may be demanded before this operation meets with universal approval.

If, as we propose, subtotal section of the sensory root is to be the adopted procedure, we must accept as our premise in this thesis that the Gasserian ganglion anatomically and physiologically is not a single but several distinct units, representing respectively the ophthalmic, maxillary and mandibular portions. The question at once arises whether there is any justification for this conception. The clinical evidence is at least suggestive. How infrequently the ophthalmic division is involved as the initial seat of the pain distribution is well known, and in the occasional case where there is an overflow of pain from the second or third to the first division, pain in the latter is inevitably relieved when pain is controlled at its original source.

Viewed phylogenetically it is interesting to note, as pointed out by van Valkenberg [4], that in certain animals there is a fairly distinct separation of the nucleus of the ophthalmic portion from that of the maxillary-mandibular portions, so that the fibres of the former can be traced to a separate origin in the brain-stem. Furthermore, it is well known that in certain lower forms of life, as in fishes and reptiles, there is an entirely separate ganglion for the ophthalmic division.

Thus from our knowledge of the clinical expression of trigeminal neuralgia in man, and from our knowledge of the anatomy of other species, *a priori* evidence for our premise would seem more than suggestive. For further substantiation, a study of the morphology of the Gasserian ganglion and the sensory root in man obviously was the next logical step. The pursuit of this investigation forms the basis of this contribution.

The Morphology of the Gasserian Ganglion. By Edward Whitehead, M.D.

This morphological study of the Gasserian ganglion in the human embryo was undertaken to determine whether or not there exists, in the early stages, any evidence of structural independence of the different portions of the ganglion and its sensory root. Since the fibres of the sensory root arise from the ganglion cells located in the Gasserian ganglion, the arrangement of these fibres in the root must, in large measure, be governed by the topographical arrangement of these cells. And since the ganglion has acquired a definite form and reached a stage of rather

advanced development before the fibres which form the root appear, it was thought that a study of the morphology of the developing ganglion, with special attention to the arrangement of the ganglion cells, would most likely throw some light on the topography of the root bundles. It was for these reasons that the work was centred mainly upon the morphology of the cellular part of the developing trigeminal ganglion.

The results of this study show that the semilunar ganglion in the human embryo, from the time that it can first be definitely outlined, is never completely separated into portions corresponding to the ophthalmic, maxillary and mandibular trunks. The ganglion is at first a continuous, compact, oval mass. As its cells proliferate it becomes more lobulated in form, and from the seventh to the tenth week the three portions come to be partially separated from one another. From the tenth week on, the evidence of division becomes progressively less marked, so that by the twenty-eighth week the contours of the three parts blend almost imperceptibly with one another. On the other hand, it is true that the cephalo-medial third of the ganglion belongs exclusively to the ophthalmic apparatus, the central portion to the maxillary division, and the latero-caudal third to the mandibular division. It is of further interest to note that by following the transformation of the ganglion it has been possible to determine factors which finally cause it to be semilunar in shape.

This study begins with embryos about 4 mm. long (end of fourth week), at which time the Gasserian ganglion is a well-defined structure whose borders can be easily distinguished from the surrounding mesoderm. A complete and detailed study of the Gasserian ganglion up to that period of development has been made by Bartelmez (in a paper published jointly with Evans [2]), whose manuscript the author has been privileged to read. He shows that this ganglion has a twofold origin: first, from the cranial neural crest, and secondly from the overlying ectoderm of the side of the head. According to him, the first contribution towards its formation is that portion of the neural crest which migrates from the midbrain and hindbrain levels during the 7 to 13-somite period. The cells of this portion of the crest, which he terms the "primordium of the Gasserian ganglion," become spread out beneath the overlying ectoderm, which has already become considerably thickened. The second contribution to the ganglion is from this thickened ectoderm. Some of the cells of this area migrate inward and join the Gasserian primordium. Apparently this inward migration takes place at two different stages

of development. The first occurs during the 9-somite stage, and the second during the 15-somite stage, there being a short interval, represented by Bartelmez's 11 to 13-somite embryo, during which there is no inward migration. The parts played by these two types of cells in the later development of the Gasserian ganglion, according to Bartelmez, are not known. Stone, in his experimental studies on amphibia, showed that the ectodermal element was necessary for the development of the Gasserian ganglion in amblystoma, but whether this holds true for man also, or whether, as Landacre believes, the crest is the chief factor, has never been determined. Bartelmez suggests that one of the types may give rise to the ganglion cells proper, and the other to the capsular and sheath cells, stating that, "if the conclusions to which Stone's work on amphibia points hold true for the human, namely, that all the general cutaneous components of the cranial ganglia come from placodes (ectoderm), then it will be necessary to consider that the large contribution of the crest to the Gasserian ganglion develops into capsular and sheath cells." Certainly there is no evidence leading us to believe that any one of the ultimate three great divisions of the trigeminal nerve comes especially from either one or the other of these two types of cells.

Allen [1] has recently published a paper concerning the localization in the semilunar ganglion of the cat. This author studied the chromatolysis of the ganglion cells in adult animals following section of the afferent trunks. With that procedure he was able to show definite localization in the ganglion corresponding to the three great trunks, and found that in the cat the mandibular trunk is somewhat more definitely localized than are the ophthalmic and maxillary trunks. The excellent paper of Dixon [3] on the development of the branches of the fifth cranial nerve in man has been of much assistance.

Before entering upon the details of this investigation I wish to acknowledge my obligations to Dr. Charles H. Frazier, of the University of Pennsylvania, at whose suggestion this study was undertaken, and whose aid and constant advice have been of the greatest value.

Material and Methods.

The list of human embryos utilized in the present study is given in the accompanying table :—

EMBRYO STUDIES.

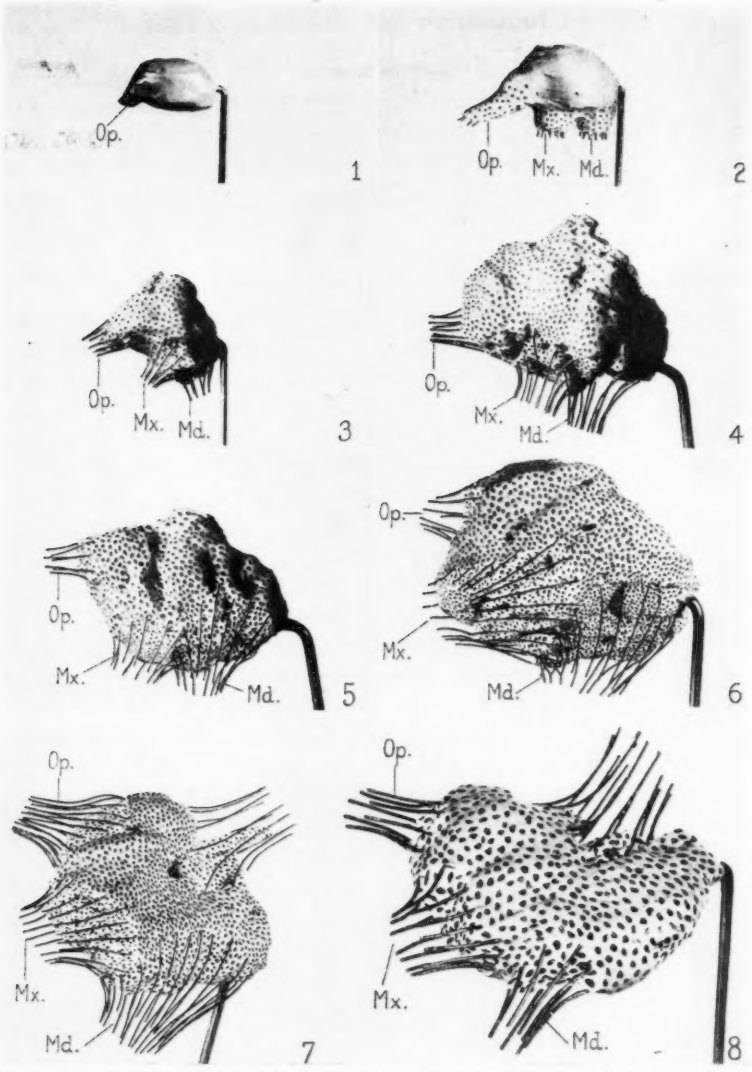
Embryo	Crown-rump length mm.	Age in weeks
No. 2,841	4·85 ..	4
,, 3,384	8·3 ..	6
,, 940	14·0 ..	7
,, 460	21·0 ..	8
,, 3,419	43·0 ..	10
,, 84	50·0 ..	11
,, 1,455	70·0 ..	12
,, 1,656	80·0 ..	13
,, 2,519	237·0 ..	28

These embryos belong to the Carnegie Embryological Collection and had all been prepared in serial sections. Wax-plate models were made (after the Born method) of the ganglion of either one or both sides of the embryo. In making the models the cellular part of the ganglion was distinguished from the fibres and nerve trunks. In general this was easily done, as these structures have sharp boundaries. In figs. 1—8 is shown the series of models of the left ganglion at each stage, as viewed from the lateral or dorsal surface. The models were made at various magnifications; in the figures, however, they are all brought to a common magnification, so that they may be directly compared. For later stages it was found advantageous to make dissections of the ganglion and its nerve trunk under the binocular microscope. A ventral and a dorsal view of such a preparation are shown in figs. 13 and 14 respectively.

Although this study is concerned primarily with the general form of the ganglion, it was found necessary to determine some of the histological factors by reference to Cajal preparations, such as can readily be made with embryonic material from the pig. In all of the stages studied in the human, such control series were examined in pig embryos, in which the nerve cells were selectively stained.

For the use of this embryonic material, and for the facilities of the Carnegie Embryological Laboratory, I am deeply indebted to the Director of the Laboratory, Dr. George L. Streeter, whose many helpful suggestions and whose constant aid has made the completion of the work possible.

Description of Stages. Fourth Week.—In embryos about 5 mm. long the Gasserian ganglion is marked off from the mesoderm and consists of a mass of closely packed cells situated in the upper part of the mandibular process, lying close to the ectoderm, which in this region is considerably thickened. It is nearly oval in shape, its cephalocaudal diameter being almost twice as great as its other diameters (see fig. 1). The ganglion is polarized; its proximal pole lies in contact with the neural tube at the pontine angle and its distal pole constitutes its



FIGS. 1-8.—Models of left semilunar ganglion, viewed from the lateral surface. These models were reconstructed from a series of human embryos of various stages of development. Although the ganglion consists, at all stages, of a continuous mass of cells, it is possible to recognize its three divisions, particularly the ophthalmic, which is more precocious in its development than the other two. Approximately the same enlargement is used in each case, so that the models may be directly compared for increase in size. Since in making the photographs the models were tilted at slightly different angles, the perspective obtained exaggerates some of the dimensions. This is particularly so in fig. 6. The wires incorporated in the models are intended to show the size and direction of the fibre trunks.

The ganglion is at first roughly oval (figs. 1-3), and after changing to a flattened spheroid (figs. 4-6), finally assumes the hollowed out, semilunar shape (figs. 7-8) characteristic of the mature ganglion. Fig. 1, embryo No. 2,841, 4·85 mm.; fig. 2, embryo No. 3,385, 8·3 mm.; fig. 3, embryo No. 940, 14 mm.; fig. 4, embryo No. 460, 21 mm.; fig. 5, embryo No. 3,419, 43 mm.; fig. 6, embryo No. 84, 50 mm.; fig. 7, embryo No. 1,455, 70 mm.; fig. 8, embryo No. 1,656, 80 mm. Enlargement approximately 22 diameters.

ventral border, along which the three trunks will later emerge. Although there are no surface markings, from its general shape and position it is evident that its cephalic part is ophthalmic, and the middle and caudad portions are maxillary and mandibular respectively.

On its dorso-median surface there is a small cellular elevation or ridge, not shown in the illustration, the precursor of the sensory root, which projects inward so as to lie against the marginal zone of the neural tube at the pontine angle, immediately opposite the first and second rhombic grooves of the ependymal and mantle layers. Apparently the only connection the ganglion has with the neural tube at this stage is one of apposition, as no connecting fibres can as yet be identified.

As we approach the ventral border of the ganglion the cells become more loosely arranged, and those of the anterior part, or ophthalmic region, are continued cephalad as a separate cellular process which extends for a short distance towards the orbital region. The maxillary and mandibular regions do not extend ventrally as separate cellular processes, but as one mass are soon lost in the surrounding mesoderm.

The ganglion is composed of oval cells which have only a very small amount of cytoplasm and which apparently have not as yet developed fibres. Throughout the greater part of the ganglion the cells are closely packed together, and nowhere is there any evidence of the grouping or cluster formation which occurs in the later stages.

Ramifying through the substance of the ganglion are small capillaries which empty into the large primary head vein as it passes across the median surface of the ganglion.

Sixth week.—In embryos about 8 mm. long the ganglion is much the same in shape as in the previous stage, the chief differences being the formation of additional cellular processes along its ventral margin (see fig. 2). The ectoderm overlying it is no longer noticeably thickened. The ganglion has become approximately four times as large as in the 5-mm. embryo; this is due mainly to proliferation of the cells, the presence of fibres and the invasion of capillaries playing a relatively small part. The dorso-median ridge, which lies against the pontine angle, is relatively much larger than in the previous specimen, and emerging from between the cells are many fibres which enter into the marginal zone of the neural tube, opposite the first and second rhombic grooves. These form the descending or spinal tract. Along its ventral border the ganglion has now arranged itself into three separate processes by the downward growth of cells. The anterior

process is a cephalad continuation of the ophthalmic region of the ganglion and may be called the ophthalmic cellular process. The middle and posterior processes respectively are ventral continuations of the maxillary and mandibular portions and may be called the maxillary and mandibular cellular processes, which are the precursors of those nerves.

The ophthalmic cellular process is much the larger, still maintaining the precocity exhibited by it in the earlier stage. It extends cephalad for a considerable distance and the fibres emerging from it form the ophthalmic nerve, which can be traced to the region above the developing optic vesicle. The maxillary and mandibular cellular processes extend ventrally for a short distance, lying very close to each other. Fibres emerge from each, which can be traced into the condensed tissues of the maxillary and mandibular bars respectively.

Apparently at this stage about half the ganglion cells show some degree of fibre development, and all types of ganglion cells, from the simple bipolar to an occasional T-shaped cell, can be found. Coincident with the development of fibres the cells are becoming arranged in small clusters. This is brought about by the way in which the cells divide. After the cell processes have formed cell division takes place in the plane of the cell processes, and the cell itself undergoes complete division before the splitting of the processes is apparently completed. The repetition of this phenomenon gives rise to the cluster arrangement, the cells of each having for a time a common fibre trunk, which passes, by the shortest possible route, towards the nearest pole of the ganglion. Just how the fibre process running to the opposite pole arises could not be definitely determined. Apparently the fibre process of each cell gives off a branch a short distance from the cell, which joins with similar branches from other cells of the cluster to form a second common fibre trunk, which passes by the shortest route to the opposite pole. Fibres are more numerous in the ophthalmic region, and apparently the cells here are somewhat more advanced in their development than are those in the rest of the ganglion.

The ganglion has now become very vascular. It is almost completely surrounded by a network of large capillaries which send numerous branches into its substance. These vessels drain into the large primary head vein, which passes caudalward across the lower half of the median surface of the ganglion.

The fibres of the motor root arise from cells in the mantle layer of the first and second rhombic grooves, and emerge from the marginal layer immediately ventral to the entering sensory fibres. They become

arranged into a compact bundle which passes caudalward across the median surface of the ganglion and joins with the fibres of the mandibular nerve.

Seventh week.—In embryos about 14 mm. long the ganglion has become approximately four times as large as in the previous specimen and has rotated on its polar axis, so that its ophthalmic region is slightly nearer the midline than is its mandibular region. As can be seen in fig. 3, its shape is still roughly oval, but its proximal pole, which in the two younger specimens projected medialward against the pons, has now become considerably flattened, and that part of the pole which represents the ophthalmic region is even hollowed out into a transverse groove. This flattening and hollowing out are in reality only relative, and are due to the fact that since the 8-mm. stage growth of the ganglion has taken place mainly in a plane at right angles to its poles. The process of cluster formation, which was beginning in that stage, has been continuing and becoming more general. Cell division has been taking place in the plane of the fibre processes, and since these pass toward the poles growth has occurred mainly at right angles to these poles. The apparent hollowing out of the proximal pole in the ophthalmic region is interpreted as another evidence of the precocity of the cells in this region. These ophthalmic cells are reaching the stage of fibre development sooner and in greater numbers than are those of the rest of the ganglion, and cluster formation here is more general. Therefore growth in the plane of the poles has been more restricted in this region than elsewhere, causing this area to appear hollowed out. The proximal fibres forming the sensory root emerge from this pole and enter the marginal zone of the neural tube immediately cephalad to the apex of the pontine angle. These fibres have now greatly increased in number and the root itself has elongated, so that the ganglion is no longer in contact with the pons. Lying in the root are many supporting cells whose branching protoplasmic processes are growing between and around the fibres and arranging them secondarily into bundles.

The ophthalmic, maxillary, and mandibular cellular processes are still present along the ventral border of the ganglion, but they are relatively much smaller than in the previous specimens, being replaced by the fibres of the respective nerves. The ophthalmic is separated from the maxillary by a greater distance than is the maxillary from the mandibular.

The three regions of the ganglion are now indicated by grooves on its surface. On the lateral surface are two dorso-ventral grooves roughly marking off the ganglion into anterior, middle and posterior

thirds. The anterior groove is much the more distinct and marks off the ophthalmic region from the maxillary. The posterior groove is very shallow but indicates the line of junction of the maxillary and mandibular regions. On the median surface also there are two grooves which correspond to the two on the lateral surface.

A much greater proportion of the cells have developed fibres, and everywhere throughout the ganglion the cells have become arranged in clusters. The central processes from these cells pass by the shortest possible route to the proximal pole and thence into the sensory root. The peripheral processes pass by the shortest route to the nearest surface of the ganglion. They then pass ventralward along the surface to the ventral border of the ganglion, where they become collected around the nearest of the three ventral cellular processes to form the ophthalmic, maxillary and mandibular nerves. By this arrangement a cell located in any given part of the ganglion sends its proximal process upward into a corresponding part of the root and its peripheral process out into the corresponding peripheral nerve. That is to say, a cell located in the anterior third, or ophthalmic region, of the ganglion, sends its proximal process upward into the anterior third of the root and its peripheral process passes out into the ophthalmic nerve. This arrangement exists, also, in the maxillary and mandibular regions, so that each of the peripheral nerves is represented in its corresponding anatomical part of the ganglion and its corresponding anatomical area in the sensory root.

The network of thin-walled blood-vessels surrounding the ganglion has become more extensive and a greater number of branches penetrate into its substance. These vessels drain into the primary head vein, which bears the same relation to the ganglion that it did in the two younger embryos.

The motor root now emerges from the neural tube almost cephalad to the point of entrance of its sensory root. Otherwise, its relations to the ganglion are the same as in the younger specimens.

Eighth week.—In embryos about 21 mm. long the ganglion is still situated immediately ventral to the pontine angle, but it has rotated slightly farther on the axis of its poles, so that the ophthalmic region is now considerably nearer the midline than is its mandibular region. It has become approximately seven times as large as in the preceding specimen, its transverse diameter having greatly increased in proportion to its cephalo-caudal diameter (fig. 4).

The apparent flattening or hollowing out of its proximal pole has not greatly increased over the 14-mm. embryo, but the transverse groove

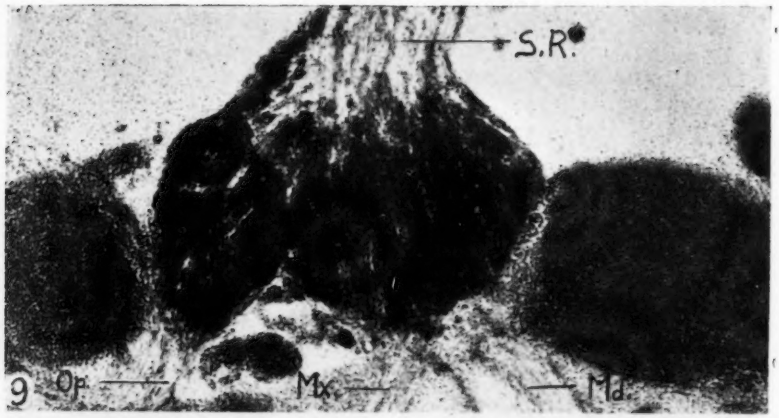
in that part of the proximal pole which overlies the ophthalmic region has become relatively much deeper.

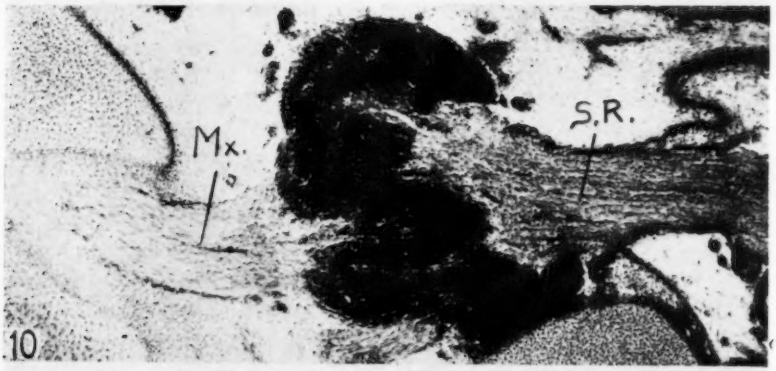
The fibres of the sensory root have greatly increased in number and are now definitely arranged in numerous small bundles, which, as they pass upward toward the pons, retain an almost constant relationship with one another. This grouping of the fibres is a secondary arrangement and has been brought about by the supporting cells growing in between and around the fibres.

The ophthalmic, maxillary, and mandibular ventral cellular processes have now disappeared, the areas occupied by them in the younger specimens now marking the sites of the formation of the three main nerves, as will be described later.

The grooves on the lateral and medial surfaces of the ganglion indicating the three regions have become more pronounced, and the ophthalmic region, as indicated by these grooves, is much more distinctly marked off than is either of the others, as can be seen in fig. 4. A greater number of the ganglion cells have developed fibre processes and cluster formation has now become almost general throughout the ganglion. The centripetal fibre processes from these cells pass by the shortest route through the substance of the ganglion to the proximal pole, where they emerge to form the sensory root. The peripheral processes from the cells in the ophthalmic region, after reaching the surface of the ganglion, become collected together at the extreme cephalad end of the ganglion to form the ophthalmic nerve, while the peripheral fibres from cells in the maxillary and mandibular regions become collected into their respective nerve-trunks immediately ventral to their corresponding regions, so that the site of formation of the ophthalmic trunk is a considerable distance from that of the maxillary trunk, while the maxillary and mandibular trunks form very close to each other. The maxillary and mandibular trunks form so close to each other that there is a considerable area on the ventral surface of the ganglion common to both, and many fibres from cells in the maxillary region find their way into the mandibular trunk and vice versa. The site of formation of the ophthalmic trunk is so far removed from that of the maxillary trunk that there is much less opportunity for overlapping of fibres here.

The vascularity of the ganglion has become more striking. The surrounding network of thin-walled vessels now sends numerous branches into its substance. Many of these branches are continued upward into the sensory root, where they can be seen lying between the fibre bundles.





FIGS. 9-11.—Photographs of sections through the semilunar ganglion at different stages in its development, showing how it becomes transformed from a roughly oval to a semilunar mass, from the hilum of which emerge the fibres of the sensory root proceeding to the brain. The peripheral fibres make their way to the convex side of the ganglion and pass down over its surface to become assembled in the principal nerve trunks. Fig. 9 (embryo No. 1,267, 14 mm.) is a mid-sagittal section through the ganglion showing the peripheral fibres coursing along the surface to become collected into the three nerve trunks. × 71. Fig. 10 (embryo No. 972, 37 mm.) shows the origin of the maxillary nerve. The lobulated, cup-shaped character of ganglion is typical for this stage of development. × 53. Fig. 11 (embryo No. 1,455, 70 mm.) is a sagittal section through the ophthalmic portion of the ganglion. Sensory root arises from hilum of ganglion and passes (to reader's right) over the cartilaginous capsule of the cochlea. The peripheral fibres can be seen passing over the surface of the ganglion to unite as the ophthalmic nerve (to the left). × 43.

The motor root now emerges from the pons immediately cephalad to the entering sensory root. Its relations to the ganglion are the same as in the preceding specimens.

Tenth and eleventh weeks.—Up to this time the cells of the ganglion are arranged more or less in a solid mass, changing from an oval form to an oblate spheroidal mass. As we have described, one can see a flattening, and even a hollowing out, of the proximal pole, from which emerge the fibres of the sensory root. In the stages which we are now taking up, this hollowing out becomes much more marked, and the comparatively solid ganglion mass becomes converted into a raspberry-like cup, the concave side of which is directed towards the brain and the convex side toward the periphery. In this transformation the ophthalmic portion continues more precocious than the rest of the ganglion. Together with this general change in form there is a gradual rotation of the ganglionic mass on the axis of its cephalo-caudad diameter, so that the surface that was originally lateral gradually assumes a dorsal position.

In the 43-mm. embryo the proximal pole of the ganglion, which in the last two specimens described was considerably flattened, has now become hollowed out into a deep pit (fig. 10), and that portion of the pole which represents the ophthalmic region is even more deeply hollowed out than is the rest of the pole. This is almost entirely relative, and is due to the fact that the growth of the ganglion has taken place largely in a plane at right angles to the sensory root. As has been previously described, owing to the way the cells divide growth has occurred mainly at right angles to the fibre processes. The central processes pass straight to the proximal pole, and, because they are sooner enmeshed by the supporting cells, become more firmly anchored than do the peripheral processes which pass to the surface of the ganglion. Therefore, with these central processes relatively anchored at the proximal pole, and with growth taking place almost entirely at right angles to these fibre processes, the ganglion has grown, as it were, around its central pole, causing this region to appear hollowed out and giving the general cup-shape to the ganglion mass (fig. 12).

The fibres of the sensory root are still arranged in numerous small bundles. Apparently there is very little intermingling of these bundles as they pass upward to the pons. The sensory root has elongated considerably, so that the ganglion, though still ventral to the pontine angle, is relatively farther from the mid-line than it was in the younger specimens.

The three regions of the ganglion are still indicated by the grooves

on its lateral and medial surfaces and, as in the previous specimens, the ophthalmic region is the most distinctly set off, as can be seen in fig. 5.

Except for the further changes that have occurred in its shape, the ganglion in the 50-mm. embryo is still very much the same as in the 43-mm. specimen (fig. 6). The cells have continued to divide in the manner described above, and as a result the ganglion has become so flattened out as to have become almost saucer-shaped. No matter what the plane of section, its cross-section would appear semilunar. It has the appearance of having a hilum, which is occupied by the sensory root, as is well shown in fig. 10. The peripheral fibres, on the other hand, pass to and along the surface of the ganglion in an orderly fashion and become collected together to form the three trunks.

Except for the anterior groove on the lateral aspect, the surface is

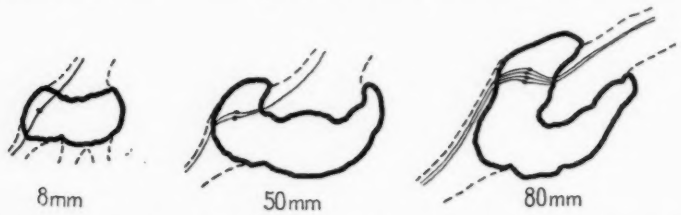


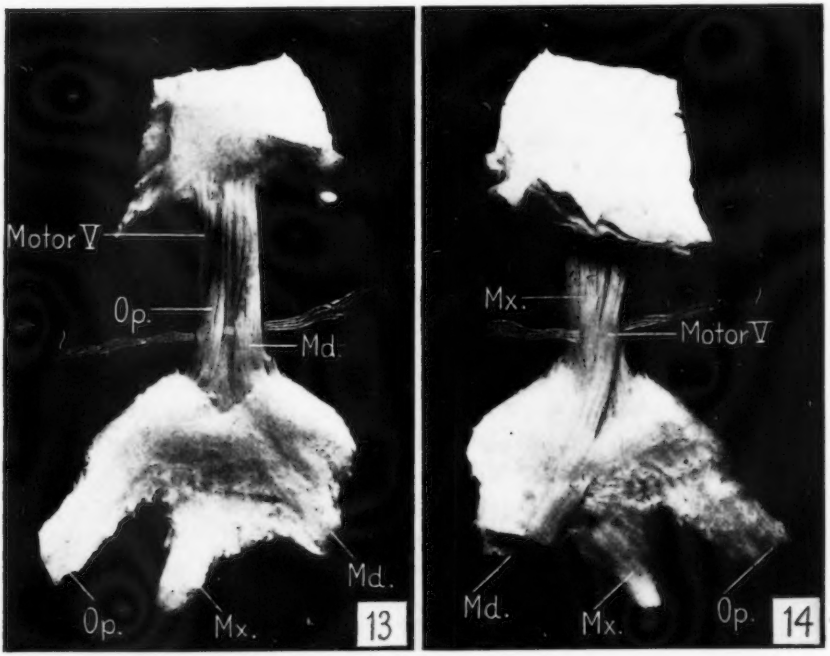
FIG. 12.—Schematic drawing to show how the prevailing manner of cell division in the semilunar ganglion results in its growth in a plane transverse to the axis of the nerve, thereby bringing about its typical semilunar shape. The cell processes reach the surface by the shortest possible route.

no longer marked off by primary delimiting furrows, but is irregularly lobulated by the small masses of proliferating centres.

Thirteenth and fourteenth weeks.—In fœtuses having a crown-rump length of 70 to 80 mm., due to the pressure exerted by the rapidly developing cerebral hemispheres above the saucer-shaped ganglion has become folded upon itself, very much as one closes a half-open book, so that the dorsal and ventral walls of the hilum are brought close to each other. At the same time, the rotation of the ganglion in its cephalo-caudal diameter has continued, so that the ganglion now presents more nearly dorsal and ventral surfaces. (See figs. 7 and 8.)

Apparently growth is now taking place more rapidly in the maxillary and mandibular regions, as this part of the ganglion has become proportionately much larger than it was in the younger specimens. As a result of this, the sites of formation of the maxillary and mandibular nerves are becoming farther removed from each other, so that in the 80 mm. embryo the three trunks form almost equidistant.

Twenty-eighth week.—For the purpose of studying the form of the ganglion in an older fœtus dissections were made of several specimens, one of which is shown in figs. 13 and 14. Here it will be seen that the ganglion has acquired practically the mature form and position. The fibres of the sensory root emerge from the hilum of the ganglion as numerous small bundles. These bundles, as they pass upward toward



FIGS. 13 and 14.—Ventral and dorsal views of a dissection of the left semilunar ganglion of a human fœtus (No. 2,519), 238 mm., crown-rump length, with an estimated age of 28 weeks. The sensory root can be seen emerging from the hilum of the ganglion, and the different portions of the root are indicated by a wisp of silk thread inserted between the maxillary on the one hand, and the ophthalmic and mandibular on the other. The surface of the ganglion, when looked at under the binocular microscope, can be seen to be covered with a sheet of fibres which are passing peripheralward to form the individual nerve trunks. The origin of the motor division can be seen in fig. 13, and in fig. 14 it can be seen to pick up processes from the maxillary portion of the ganglion on its way to join the mandibular nerve.

the pons, run more or less parallel, with very little interchange of fibres. In fig. 13 a thread has been passed under the bundles from the ophthalmic and mandibular regions of the ganglion and over those from the maxillary region, in order to illustrate better the fact that,

in the main, each of these regions sends its centripetal fibres upward in a corresponding anatomical third of the root.

Under the binocular microscope one can clearly see the peripheral fibres of the ganglion emerging from among its cells and passing over its surface in an orderly manner to become collected into the nearest of the three peripheral nerves. In this way one can recognize that the three divisions of the ganglion are more or less clearly separate from each other. The middle (maxillary) division occupies less than one-third of the dorsal surface of the ganglion, but on the ventral side it occupies more than one-third. The opposite is true with respect to the third (mandibular) division. The ophthalmic is equally represented on the ventral and dorsal surfaces of the ganglion.

The motor root arises from the pons immediately cephalad to the entering sensory root. As it emerges from the brain its fibres are arranged in small bundles, and three or four of these bundles, which apparently are the fibres from the mesencephalic nucleus, emerge at a more dorsal level than the bundles of the major part of the root. This can be seen in fig. 13. From its point of emergence the motor root passes ventral to the sensory root and across the ventral surface of the ganglion to join with the mandibular trunk. It is interesting to note that in the specimen illustrated the motor root, as it crosses the ventral surface of the ganglion, is joined by peripheral sensory fibres from the maxillary region of the ganglion.

Summary.

(1) In the human embryo, from the fourth week to term, the Gasserian ganglion, in its gross form, is a single fused mass.

(2) The ophthalmic portion, though at no time a completely detached unit, is differentiated from the remainder of the ganglion by being more precocious in its development. The cells in this region develop their fibre processes earlier and the cells become arranged in clusters sooner than do the cells of the other regions. The ophthalmic ventral cellular process, the precursor of the ophthalmic nerve, develops earlier than do the maxillary and mandibular processes. Associated with the earlier differentiation of the ophthalmic portion of the ganglion, surface markings occur as grooves on the lateral and medial surfaces, which set off this region from the remainder of the ganglion.

(3) The ophthalmic region is also differentiated from the remainder of the ganglion by the fact that the site of formation of the ophthalmic

nerve is widely separated from that of the maxillary and mandibular nerves, which form very close to each other.

(4) Owing to the fact that the proliferating cells of the ganglion tend to split in the axis of the cell processes, the increase in the size of the ganglion is predominantly in a plane transverse to the main axis of the nerve.

(5) The manner in which the cells divide is an important factor in determining the eventual semilunar shape of the ganglion. It appears to be a phenomenon analogous to that which occurs in the formation of the inferior olive and perhaps of the convolutions of the brain.

(6) The ganglion is semilunar, as seen both from its dorsal surface and in sagittal section.

(7) Consequent upon its semilunar shape, the ganglion is characterized by a hilum from which the sensory root emerges. The peripheral processes of the ganglion cells reach the nearest point on the surface of the ganglion. They then pass along the surface in an orderly manner and become collected into the nearest of the three nerve trunks.

(8) The fibres of the sensory root run parallel and become arranged in separate bundles by the enveloping supporting tissue and do not tend to intermingle.

(9) In the course of its development, the ganglion undergoes a rotation, whereby its lateral surface finally becomes its dorsal surface.

(10) In the early stages of development the motor root emerges from the pons immediately ventral to the entering sensory root; as development proceeds this relationship changes, so that the point of emergence of the motor root becomes immediately cephalad to the point of entrance of the sensory root.

(11) The motor root emerges from the pons as separate bundles at two different levels, and the fibres emerging from the dorsal level are apparently of the mesencephalic nucleus.

(12) The motor root, as it passes across the median surface of the ganglion, is joined by peripheral sensory fibres that have arisen from sensory cells in the maxillary region of the ganglion.

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A PECULIAR REFLEX PHENOMENON.

BY P. M. VAN WULFFTEN PALTHE.

MOST people have experienced at one time or another that feeling of suffocation and gasping for breath, accompanied by a curious sensation in the throat, which occurs when a strong current of air strikes full in the face. In walking against a strong wind, in driving in an open motor car not provided with a wind screen, in looking out of the window of a rapidly travelling train or aeroplane, we become conscious of this phenomenon which, in sensitive persons, only disappears after the face is covered or turned away from the wind.

If this phenomenon is more closely investigated by experimenting with a powerful ventilator air current, even a simple examination provides numerous details of the reflex act. In the first place we find an immediate catching of the breath, only a few rapid successive movements of the chest occurring. Simultaneously there is a perceptible contraction of the floor of the mouth, while the larynx first rises quickly and then falls at a slower rate. Nearly always the sound which accompanies a spontaneous swallowing movement can be heard, even at a distance. When the stimulus is applied for any length of time the person experimented with becomes conscious of a feeling of oppression, and at the same time is obliged to make movements of swallowing several times in rapid succession.

We consequently find that on irritating the skin of the face in a special manner, movements of the floor of the mouth and of the larynx occur, while respiration is abruptly arrested. These two reactions will be studied more closely after the nature of the adequate stimulus and the exact spot to which it must be applied have been determined.

RECEPTIVE FIELD.

As we have seen, a current of air received full in the face invariably causes the reflex. If we play upon the skin of the face with a small but powerful current of air, for example by means of a glass tube of about 5 mm. in diameter connected with a reservoir in which there is a pressure of two atmospheres, it is found that this has no effect when applied to the cheeks, nose, forehead or chin, but that the moment the

current of air touches the upper lip the reflex immediately occurs. In a few very sensitive persons the reflex may be also induced by spraying the lower lip just under the mucous membrane. This method of air-spraying is not a suitable means by which to localize accurately the excitable area, since the air spreads on all sides, and also because we cannot see exactly where it touches the face. A fluid spray has not these disadvantages; when directed on to the cheeks and neck it has no special effect, but as soon as the spray touches the upper lip under the nasal septum the reflex occurs. When the head is bent a little backwards, the reflex movement of the thyroid cartilage can be also distinctly seen.

With such a spray it is possible to find the exact receptive field of of the reflex, by stimulating in succession various parts of the face. It is most easily elicited by applying the stimulus to a sharply localized position of the skin of the upper lip, just under the two nostrils and the nasal septum. The edge of the mucous membrane of the septum and sometimes even the whole edge of the lip are included.

The receptive field for this reflex, therefore, is an area of skin innervated by the second branch (where the lower lip is concerned, also by the third) of the trigeminal nerve.

Nature of the Adequate Stimulus.

To have effect the stimulus must be applied over a certain extent of the surface and at the same time must be cold; mechanical stimuli and spraying with warm water are ineffective. I have been successful in producing the reflex with a cold water spray only, or still better with an ether spray or with a strong current of air. The adequate stimulus is therefore of a thermo-mechanical nature. The stimulus may be regarded as noxious to the region from which it excites the reflex.

Reaction.—The first question that arises is the nature of the visible contraction of the floor of the mouth and the movement of the larynx. Subjectively one gets immediately the conviction that we have here to do with a swallowing movement, and objectively one can easily determine that the final result of the stimulus is reflex deglutition. It is another question whether the successive muscle contractions are absolutely identical with those that occur in the bucco-pharyngeal part of normal deglutition.

Kinderman [5] and Zwaardemaker and Eykman [11] analysed the initial phases of spontaneous swallowing and registered the various movements of the larynx, floor of the mouth and soft palate. Their

curves show, generally speaking, that in the bucco-pharyngeal part of swallowing there occur :—

(1) A contraction of the muscles of the floor of the mouth.
(2) A forward and upward movement of the hyoid and larynx.
(3) An upward movement of the soft palate.
(4) An increase of pressure in the nasal cavities.

The floor of the mouth is raised by the contraction of the mylohyoid muscle, which forms a deep cavity in which the tongue rests. The tongue is then, by contraction of its muscles, pressed against the hard palate, and hardens and broadens in such a manner that at a distance of about 5 cm. from the teeth it hermetically closes all access from the front part of the mouth. The upward movement of the velum blocks the passage between the pharynx and the nasopharynx. The glottis closes and at the same time disappears under the base of the tongue, which is pressed forcibly backwards.

The movement of the tongue, beginning where it first blocks the buccal cavity, continues until it rests against the back wall of the pharynx (Kinderman). Zwaardemaker is of the opinion that it is not the movement of the velum which separates the oral part of the pharynx and the epipharynx, but that this is due to contraction of the muscles of the lateral and posterior walls of the pharynx (the pharyngeus superior and palato-pharyngeal muscles).

Miller and Sherrington [9], in their experiments on the bucco-pharyngeal phase of deglutition in decerebrated cats, came to the conclusion that the closing of the nasal cavities is not caused by the upward movement of the velum: "It could be seen clearly in all positions that after ablation of the soft palate, the tongue, by its full upward movement in the swallow, reached and pressed against the front of the roof of the pharynx, preventing any of the fluid swallowed gaining access to the nasal chambers."

However this may be, all investigators agree that at the beginning of swallowing the pharynx is completely closed to the mouth, nose and trachea, and only the entrance to the gullet remains open. It is obvious that the pharynx is not merely closed to the mouth, nose or glottis, but that at the same time the *entrance* to the larynx and pharynx is blocked to everything that might penetrate *from without*. When presently an attempt will be made to discover the biological significance of the newly-discovered reflex, it will be seen that this point is of great importance.

In order to determine whether or not the first phase of spontaneous

swallowing and that of reflex swallowing elicited by applying a stimulus to the upper lip, are identical, I employed the methods used by Zwaardemaker and Kinderman and registered the movements of the larynx, the contractions of the floor of the mouth and the pressure in the nasal cavities.

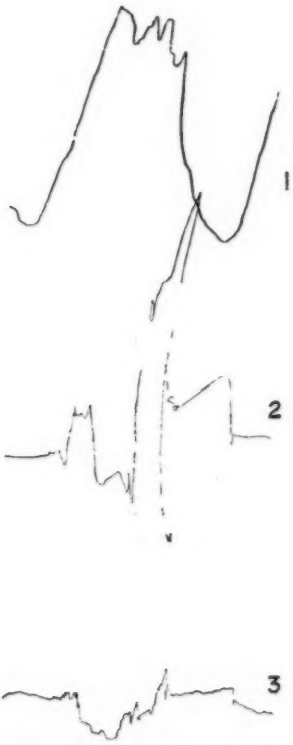

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FIG. 1.—Tracing of the movements of the larynx during the reflex swallow evoked by spraying the upper lip with water.

1. Respiratory movements: upstroke inspiration, downstroke expiration.
2. Up and downward movements of the larynx.
3. Forward and backward movements of the larynx.

Arrest of breathing during inspiration, only a few slight respiratory movements occurring. Vertical and horizontal (sagittal) movements of the larynx simultaneous.

Fig. 1 shows the laryngeal movements in normal swallowing; in figs. 2, 3 and 3A the tracings of the higher pressure in the nasopharynx and of the movement of the floor of the mouth during the spontaneous

swallowing of saliva, and in reflex swallowing elicited by applying a stimulus in the form of a strong current of air to the skin around the mouth, are represented. There is a difference in the course of the two phenomena. In spontaneous swallowing the floor of the mouth first falls slightly ("fall" in figs. 2 and 3) and then moves upwards and down-

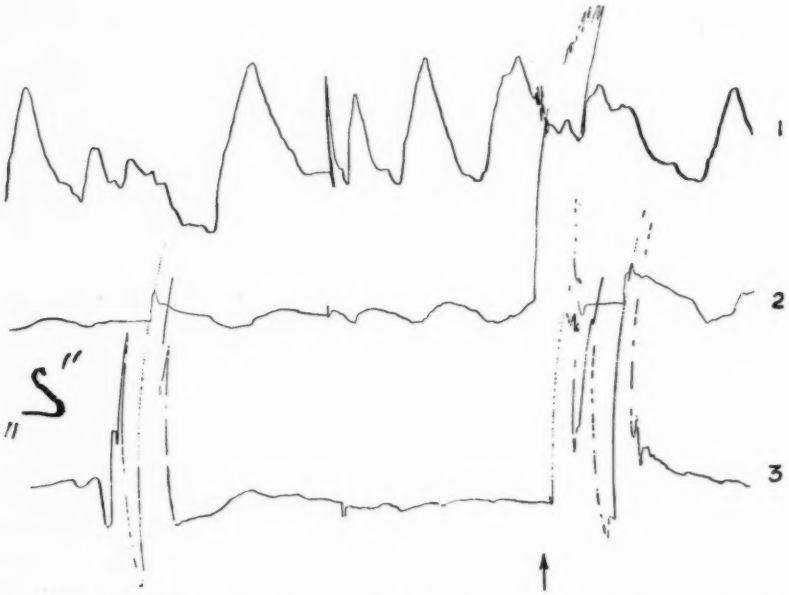

FIG. 2.—Curve XII. June 18, 1925. At S a spontaneous swallowing movement, and afterwards (at arrow) a reflex swallow elicited by spraying the upper lip with a strong current of air.

1. Respiratory movements.
2. Pressure in the nasopharynx.
3. Movements of the floor of the mouth.

In spontaneous swallowing the increase of pressure in the nasal cavities occurs a little after the contraction of the floor of the mouth, and is not very high. Increase of pressure in the nasopharynx during the reflex swallow is very considerable, and synchronous with contraction of the floor of the mouth.

wards over a considerable range; in reflex swallowing the horizontal base line immediately deviates sharply upwards. Further, the rise of pressure in the nasal chambers is in the first case very slight and occurs only some tenths of a second after the contraction of the floor of the mouth. In reflex swallowing, on the other hand, the pressure is considerably higher and is absolutely synchronous with the movement

of the floor of the mouth. Simultaneously the entrance from the mouth and nose to the pharynx is suddenly and firmly closed, the "aditus ad pharyngem et laryngem" is blocked.

All the curves show that respiration is suddenly suspended at the moment the stimulus is applied, while the spontaneous swallowing

FIG 3. FIG. 3A.

FIG. 3.—Spontaneous swallowing (S) begins at the end of the expiration. "Introductory" movement clearly perceptible; pressure in the nasopharynx hardly increased.

1. Respiratory movements: upstroke inspiration, downstroke expiration.
2. Pressure in the nasal cavity.
3. Movement of the floor of the mouth.
4. Signal.
5. Time in $\frac{1}{10}$ sec.

FIG. 3A.—Swallowing induced by spraying the upper lip with a current of air directly after the spontaneous swallowing of fig. 3. The initial movement of the floor of the mouth is absent. The reflex begins during inspiration. Pressure in the nasopharynx is very high.

of saliva or chyme always occurs at the end of an expiration (Zwaardemaker [12]). (See also figs. 1, 2 and 3.) In reflex swallowing, on the contrary, breathing may be arrested during either expiration or inspiration; as soon as the current of air or the ether spray touches the

upper lip breathing ceases, no matter what phase of respiration is in progress, and is only resumed when the stimulus is removed.

It is obvious that when the opening of the larynx is completely closed, movements of the chest and contraction of the diaphragm can have no respiratory effect. At the same time I should like to point out that we must naturally not conclude from these facts that stimulation of the trigeminal nerve can arrest breathing. Very probably a stimulus applied to a definite part of the trigeminal nerve has no direct influence on respiration, but acts only indirectly through the muscle

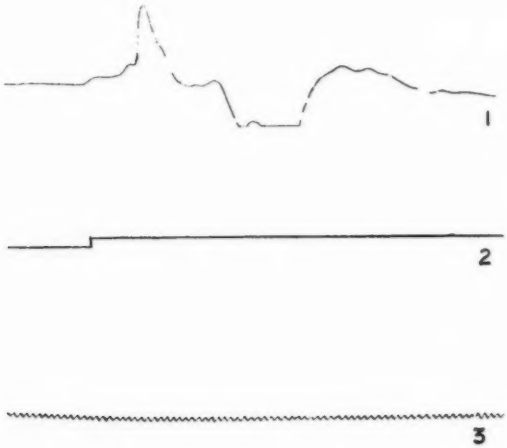

FIG. 4.—Latent period of reflex swallowing elicited by an ether spray on the upper lip. Latent period 0·28 sec.
1. Movement of thyroid.
2. Signal.
3. Time in $\frac{1}{2^{\frac{1}{5}}}$ sec.

contractions evoked in the floor of the mouth, tongue, and larynx. Miller and Sherrington, who evoked swallowing movements in decerebrated cats by stimulating the root of the tongue by dropping alcohol or water into the sinus glosso-epiglottideus, observed arrest of breathing in various phases: they are, like Kronecker, Meltzer [8], Marckwald [7], and Kitajev, of the opinion that the glosso-pharyngeal nerve is the afferent nerve for this inhibition of respiration. Marckwald has shown the faradization of the ninth cranial nerve may cause arrest of breathing in any phase.

Nerve Paths.

L. Bouman [1] believes that in animals a stimulus applied to the pharynx and epiglottis causes swallowing movements, the glosso-pharyngeal and the superior laryngeal branch of the vagus being the

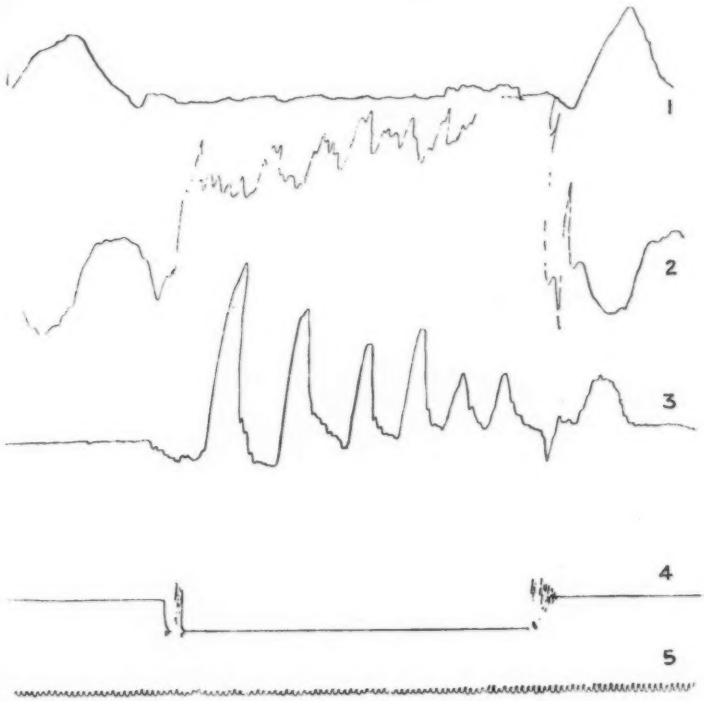

Fig. 5.—Uninterrupted stimulus (air current on upper lip) for 6·3 seconds.
1. Respiratory movements.
2. Pressure in the nasopharynx.
3. Contraction of the floor of the mouth.
4. Signal.
5. Time in $\frac{1}{10}$ sec.

Six swallowing movements and one after-discharge. Increase of pressure in the naso-pharynx 0·2 sec. after stimulus begins; contraction of the floor of the mouth, 0·7 sec. after stimulus begins. Time between the swallowing movements, 1·3 sec., 1·2 sec., 0·9 sec., 0·8 sec., 0·7 sec. Breathing is arrested during expiration, the beginning of inspiration being checked.

afferent nerves, and the motor root of the trigeminus, hypoglossus, glosso-pharyngeus and vagus the efferent. Gad [2] believes that normally the swallowing reflex is elicited from the parts of the under

surface of the palate and the region of the tonsils supplied by the trigeminal nerve; cocainization of the mucous membrane of these parts makes deglutition impossible. Swallowing can be also excited from the mucous membrane above the glottis, which is supplied by the superior laryngeal nerve.

Halliburton [4] regards the trigeminal, glossopharyngeal and the superior laryngeal as the afferent nerves, and the motor trigeminus,

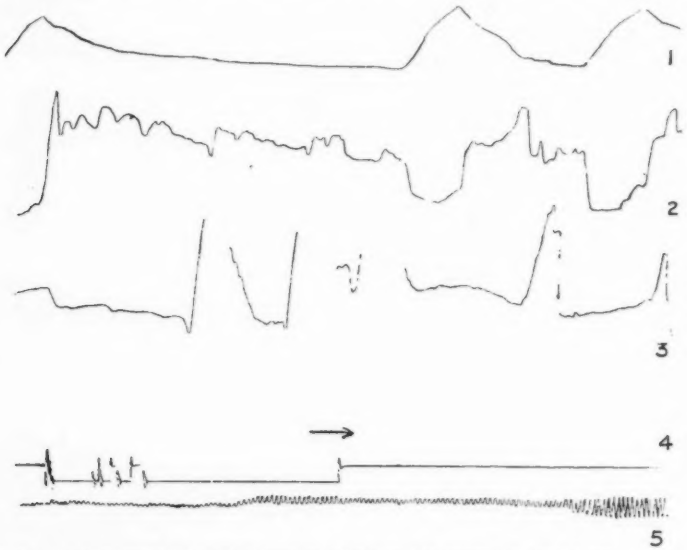

FIG. 6.—Uninterrupted stimulus (current of air on the upper lip) for 6·4 sec.
1. Respiratory movements.
2. Pressure in the nasopharynx.
3. Movement of the floor of the mouth.
4. Signal.
5. Time in $\frac{1}{10}$ sec.

Time between the five swallowing movements, 1·9 sec. and 1·51 sec., 3·5 sec. and 2·8 sec. Arrest of breathing continues one second after the stimulus has ceased and three further swallowing movements occur (after-discharge).

the bulbous part of the accessorius, the glossopharyngeus, vagus and hypoglossus as the efferent nerves. Zwaardemaker and Eykman describe swallowing as a co-ordinated reflex, the sensory nerves being, as was shown by Wassilieff's experiments on rabbits, the trigeminus nerve or the vagus, while the motor nerves are the trigeminus, hypoglossus, glossopharyngeus, vagus, accessorius group, facialis and spinal nerves.

They regard swallowing as a reflex chain, evoked by stimulating the trigeminus (in animals) or the vagus.

Waller and Provost [10] stated that reflex swallowing was not possible after intracranial section of both trigemini. They described the receptive field as an area in the neighbourhood of the tonsils, and believed that after section of both trigemini it is no longer possible to elicit the reflex. This does not agree with the latest experiments of Miller and Sherrington. "After intracranial section of both trigemini, swallowing was still excitable from the posterior part of the tongue and the pharynx, and seemingly as readily as when those nerves were intact."

Experiments made by these investigators to determine the position of the reflex centre show that in the cat very weak unipolar faradization of the fovea inferior invariably excited the reflex mechanism. "As to what morphological structure in the ventricular floor it may be which the faradization, thus supplied, reaches and stimulates in producing this result, we find difficult to judge." They consider it most probable that stimulation of the funiculus solitarius led to this result. "The fasciculus solitarius is made up of afferent fibres gathered together from the entrant glossopharyngeal and pharyngeal and superior laryngeal nerves, probably with contributions also from the fifth cranial nerves (palatine branches). Some of the afferents of these nerves are known to evoke reflex swallowing. The inferior fovea seems to be that point of the floor of the ventricle to which, in the natural unshrunken state of the floor, the fasciculus solitarius approaches closest."

From this survey of earlier investigations, it appears that in animals at least the trigeminus may be regarded as one of the afferent nerves for the reflex mechanism of swallowing, and that the linking of the afferent and efferent fibres (the "clavier spinal" of Mosso) must be situated in the medulla oblongata.

I have found no reference in medical literature to the effect that irritation of the skin innervated by the second branch of the trigeminal nerve excites reflex swallowing in human subjects, but I may mention as a curious fact that Gastrowitz and Gutmann [3] in 1875, discovered that the movements of swallowing could be produced in persons in agony by touching the cornea.

The route by which the stimulus reaches the centre from the receptive field (upper lip and nasal partition bone) and whether this passes through the Gasserian ganglion is not known, although a few clinical cases which will be dealt with later indicate that the reflex

cannot be evoked when an interruption occurs in the root of the trigeminal nerve.

Details of the Reflex Mechanism.

By means of graphic registration I first determined the latent time. The beginning of the stimulus was indicated by the breaking of an electric contact at the moment that a thin spray of ether left the syringe, which was held close to the face. At the beginning of the reaction I took the movement of the larynx, which was recorded on a kymograph by means of air transmission (see fig. 1). The longest latent

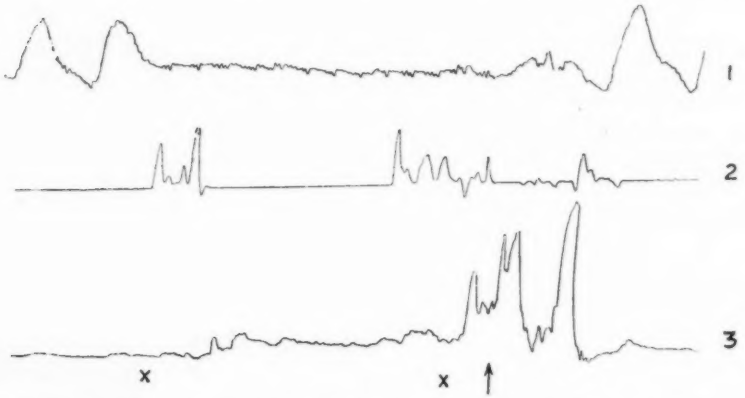

Fig. 7.—Curve V. Uninterrupted stimulus (air current on upper lip) for 10·2 sec.
1. Respiratory movements.
2. Pressure in the nasopharynx.
3. Movement of the floor of the mouth.

Increase of pressure in the nasopharynx causes upward movement of the curve. From X to X slight contractions of the floor of the mouth occur, but the full swallowing movement only takes place at ↑. Increase of pressure in the nasopharynx precedes the contraction of the floor of the mouth. Arrest of breathing is not absolute, but only very rapid and extremely superficial respiratory movements take place.

time I found among thirteen persons (each person being tested at least five times) was 0·48 second, while the shortest was 0·08 second. Zwaardemaker [13], experimenting on animals, determined this latent time in response to induction shocks to the superior laryngeal nerve. Applying the stimulus twenty times per second he found a latent period of 0·2 second; applying it forty times per second it was 0·15 second. With a single stimulus the latent time fluctuated between 0·2 second and 0·6 second.

REFRACTORY PHASE. AFTER DISCHARGE; "ALL-OR-NOTHING" LAW.

If the stimulus is applied for five to ten seconds breathing is impeded during the whole period and the pressure in the nasopharynx remains high, increasing with every swallow (see figs. 5 and 6). These swallow-

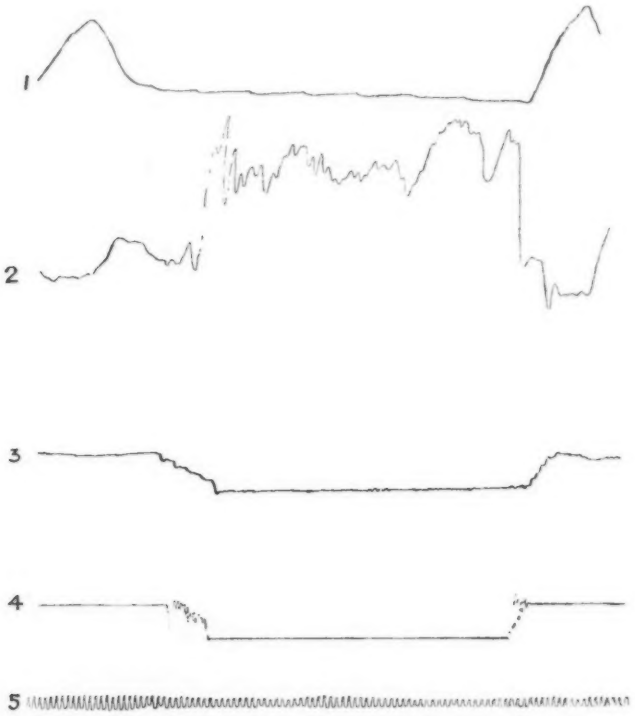

FIG. 8.—Curve X. Same test as in fig. 7. Stimulus for 5·6 sec.

1. Respiratory movements.
2. Pressure in the nasopharynx.
3. Movement of the floor of the mouth.
4. Signal.
5. Time in $\frac{1}{10}$ sec.

No swallowing movement, but increase of pressure in the nasopharynx and arrest of breathing occur. Contraction of the floor of the mouth is clearly perceptible.

ing movements follow each other at regular intervals. A refractory period occurs at intervals of about one second. I observed repeatedly that after the prolonged stimulus was removed a few swallowing movements still occurred (see especially fig. 6), the so-called "after-discharge."

With regard to the "all-or-nothing" law in connection with this reflex, one may conclude from the various tests and the curves here reproduced that once the reflex has begun the various movements follow each other uninterruptedly to the end. The curves in figs. 7 and 8 may seem an exception. It is true that in curve V (fig. 7) arrest of the respiratory movements and contraction of the floor of the mouth occur at the beginning of the stimulus, but swallowing movements only take place after an interval of six seconds; in curve X (fig. 8) although there is an arrest of respiration, increased pressure in the nose and contraction of floor of the mouth, swallowing does not occur. This was repeatedly seen and could be reproduced regularly by reducing the intensity of the stimulus; cessation of respiration, closing of the nasopharynx and contraction of the floor of the mouth occurred with a very slight excitation; the swallowing movement finally resulted from summation of the stimuli. This does not mean, however, that the "all-or-nothing" law does not apply here; as soon as the real swallowing reflex begins, it proceeds automatically to the end.

Biological Significance.

On applying to the neighbourhood of the mouth and nostrils a stimulus which might cause injury if it penetrated the larynx and pharynx, a reflex occurs which in many respects resembles the ordinary swallowing reflex, though it differs in minor respects. In the first place there is not the so-called preparatory movement, which in the case of ordinary swallowing serves to bring the chyme or saliva to the back of the mouth (see figs. 2 and 3). In the second place, the increase of pressure in the nasal chamber is much more considerable than in ordinary swallowing, and finally the reflex can commence in any phase of respiration, and not, as in the case of ordinary swallowing, only at the end of expiration.

It is only when a very strong stimulus is applied that the whole chain of reflex swallowing movements follow each other regularly to the end. When the stimulus is weaker the result is confined to arrest of breathing, closure of the nasal cavities, elevation of the root of the tongue and contraction of the muscles of the floor of the mouth. Contraction of the floor of the mouth is the essential part of the reflex; its development into a swallow is secondary and can in many cases be repressed.

The reflex should be therefore regarded as a protective mechanism which prevents anything harmful penetrating into the larynx and pharynx; a reflex which only arises when a thermo-mechanical stimulus,

as cold air or a spray of ether or cold water, impinges on the surface in the neighbourhood of the mouth or nostrils. The winking reflex which occurs when a current of cold air strikes the eye is an analogous phenomenon.

Practical Significance.

The disagreeable feeling of oppression and of tension in the muscles in the mouth and throat when driving rapidly in an open car, when looking out of the window of a train or aeroplane, or when walking against a strong wind, can be entirely avoided by covering the nose and upper lip sufficiently. Protection with the hand is not sufficient, as this cannot prevent small currents of air from penetrating to the face. Covering that part of the face with a handkerchief or something similar will always be found to answer the purpose.

Clinical Significance.

As a general rule, apart from the effect of "shock," the absence of a definite reflex indicates an interruption in the centripetal or centrifugal paths, or disease which renders the linking of these fibres difficult or impossible.

In how far the reflex described above has any localizational value, for example in distinguishing between peripheral and central disturbances of sensibility in the trigeminal areas, further investigation must decide. I may, however, mention a few observations I have recorded bearing on this question.

In a case of syringomyelia and syringobulbia with dissociated hypæsthesia in the whole area of the trigeminal nerve, the swallowing reflex could not be elicited on either side. In a case of tumour of the spinal cord, which in addition to disturbing function in the lower situated parts of the body had caused insensibility to the whole left side of the face, while the right side was not affected, I could not excite the reflex by a stimulus applied to the left half of the upper lip; the right half was normally sensitive to the stimulus and gave the reflex promptly.

In a case of loss of tactile sensation and diminution of pain and thermal sensibility on the right side of the face as a result of an affection of the Gasserian ganglion, the reflex could be obtained from both sides and apparently equally. The corneal reflex was absent on the right side and there was a keratitis neuroparalytica in the right eye.

Another case may be mentioned which perhaps throws some light on the path along which the stimulus passes from the receptive field to the centre.

On June 11, 1924, the patient fell from the box of a cab, and was carried unconscious into the Wilhelmina Hospital, Amsterdam. He bled from his right ear and vomited; his pulse was slow (40 per minute). There was no paralysis of his face. The corneal reflex was present on both sides. The swallowing reflex could be elicited normally from the left as well as from the right half of the upper lip. The patient remained unconscious for twenty-four hours and afterwards had complete amnesia for what had happened. Two days after the accident he could not close his right eye owing to a complete facial paralysis of a peripheral type. The following day he complained of a stiff feeling in the right half of his face "as if it had received an injection before the extraction of a tooth." The sensibility in the whole right trigeminal area was greatly reduced for all qualities. The jaw deviated to the right and mastication on the right was much less strong than on the left. The right corneal reflex was absent, the left weak. The swallowing reflex could not be evoked from the right side of his lip, but on stimulation of the left side it occurred promptly. During the succeeding few days the condition, as far as the reflexes were concerned, remained the same but the disorders of sensation in the trigeminal area became less apparent. On July 16 the swallowing reflex from the right was feebler than from the left (on the left it was abnormally brisk), and on July 17 a normal swallowing reflex could be elicited from both sides.

One might assume in this case a fracture at the base of the skull, owing to which a few days afterwards a local process, possibly hæmorrhage, temporarily affected the root of the trigeminal nerve. This case would therefore seem to indicate that the centripetal part of the reflex path passes through the Gasserian ganglion and the root of the trigeminal nerve.

Another case may be mentioned from which it appears that the reflex can also be abolished when there is no disturbance of sensibility in the area which is supplied by the second branch of the trigeminus.

The patient, 55 years old, on September 15, 1924, presented choked discs, palsies of the external recti, more apparent on the right than on the left, and absence of the corneal reflex on the left side. She complained of headache, giddiness and diplopia. She was quite deaf in the left ear, and caloric stimulation of this ear did not produce any vestibular reaction; examination in the rotation chair also showed complete inactivity of the left vestibular apparatus.

The diagnosis made in the Psychiatric-Neurological Clinic, Utrecht, was a cerebello-pontine angle tumour. On October 2, 1924, a palliative decompression operation was performed, a piece of the occipital bone around the foramen magnum being removed and the dura incised.

October 13. Visual acuity has not improved, the patient vomits much. The position, as far as the cerebral nerves are concerned, is the same as before the operation.

It is impossible to evoke the swallowing reflex by spraying the upper lip and the nasal septum on either the left or the right side.

In this case a tumour which affected the fifth, sixth and eighth cranial nerves of the left side, and also produced some weakness of the right abducens, led to the disappearance of the swallowing reflex. No disorders of spontaneous swallowing existed, nor could any change in sensation be detected in the area supplied by the second branch of the trigeminal nerve.

SUMMARY.

(1) By means of a certain form of stimulation applied to a part of the skin and mucous membrane supplied by the second branch of the trigeminal nerve a reflex can be elicited which consists in:—

(*a*) Arrest of breathing in any phase.

(*b*) Movement of the floor of the mouth and of the root of the tongue.

(*c*) Movement of the larynx.

(*d*) Increase of pressure in the nasal cavities.

(2) This reflex resembles in many respects the swallowing reflex.

(3) The centripetal part of the reflex path is probably formed by the second branch, the Gasserian ganglion and the root of the trigeminal nerve.

(4) Biologically this reflex may be considered as a protection against the entrance of harmful substances into the larynx and pharynx. It acts also during unconsciousness.

(5) The unpleasantness which arises when a strong current of air strikes the face is explained by this phenomenon.

(6) This "reflex swallow" may have localizational value in distinguishing between disorders in the trigeminal sensibility of peripheral origin and those due to more centrally situated lesions, above the linking centre of these cerebral nerves.

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THE MECHANISMS OF SPEECH AND DEGLUTITION IN PROGRESSIVE BULBAR PALSY.[1]

BY MACDONALD CRITCHLEY, AND CHARLES S. KUBIK.

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INTRODUCTION.

THE disturbances of function of the larynx and pharynx met with in disorders of the central nervous system are notoriously difficult to analyse; investigation into the morbid physiology entails a knowledge of many points in the normal working of these functions, which are still difficult of comprehension. The analysis of pathological cases, combined with investigations along the lines of comparative morphology and embryology, may contribute to our knowledge of the normal physiology. For this purpose, cases of bulbar palsy, arising in the course of amyotrophic lateral sclerosis, have been chosen. The choice was determined more by opportunity than by deliberation, as there are especial difficulties peculiar to Charcot's disease which arise when investigating these phenomena.

References to the relative affection of the bulbar muscles in this disease are scanty, and there are even fewer observations upon the morbid physiology of the larynx and pharynx. Hallopeau, in his thesis of 1875 on bulbar palsy, cited several cases in which paralysis of the laryngeal musculature occurred in the course of progressive muscular atrophy. Fatty changes were met with in the affected muscles. In his own words: "Les troubles de la phonation consistent dans une altération de la voix causée par un état parétique des muscles intrinsiques du larynx; rarement la voix est complètement éteinte, elle est seulement

[1] From the wards and laboratories of the National Hospital for the Paralysed and Epileptic, Queen Square, London.

affaiblie. . . . M. Duchenne a pu constater au laryngoscope le relâchement des cordes vocales."

Dejerine [7], in 1883, examined many muscles of the pharynx and larynx in two cases of bulbar palsy occurring in the course of amyotrophic lateral sclerosis. His first patient was a female, aged 54, who presented the ordinary manifestations of the disease. She was unable to protrude her tongue; her speech was nasal and "blowing" in timbre, and she was unable to articulate consonants. There was considerable difficulty in swallowing both liquids and solids. Histological examination of the affected muscles showed simple atrophy of the fibres with degenerative changes, both fatty and granular in type. In the more affected muscles, the appearance was that of abundant sarcolemma nuclei without any muscle substance. These changes were markedly present in the orbicularis oris and palate; the tongue was also atrophied, but the microscopical appearance showed much less change than was anticipated from clinical observation. The subhyoid and laryngeal muscles were but slightly affected, the constrictors of the pharynx not at all.

His second patient was an old lady, aged 74, whose tongue was immobile; she had marked dysphagia with regurgitation of fluids and she was unable to pronounce linguals or labials. Marked atrophic changes were revealed in the buccinator, the orbicularis oris and in the palatal muscles. The mylohyoids, the pterygoids, the pharyngeal and laryngeal muscles were affected, but to a lesser degree.

Collier [6] in 1903 reviewed the whole subject in a valuable paper based upon a clinical and pathological examination of eleven cases of bulbar palsy. He emphasized the relatively severer implication of the extrinsic muscles. In all of his cases the linguals were very grossly affected, the glossi were almost as atrophic, the mylohyoids and anterior bellies of the digastrics were markedly affected. The depressors of the hyoids also showed gross changes. The palatal muscles, with the exception of the palato-glossi, had undergone very little atrophy; in the pharyngeal constrictors there were scarcely any changes. In the laryngeal muscles there was either no affection, or at the most there were a few atrophic fibres at the angles of the muscle prisms. Collier's conclusion was that the dysphagia and dysphonia arising in the course of the disease were referable to the atrophic paralysis of the supra- and infra-hyoid muscles, rather than to affection of the intrinsic muscles of the palate, pharynx and larynx.

Chapter I.—Physiological Considerations.

In analysing the mechanism underlying the phenomenon of deglutition many factors present themselves for consideration. It must be realized that the act is one of the utmost complexity, involving the co-ordinate functioning of many sets of muscles in successive stages, and that it embraces the activity of somatic and skeletal, as well as of unstriped muscles. Secondly, the mechanism varies in an individual case, with the consistency of the substance to be swallowed, solids and liquids each requiring its own special process. Thirdly, the mechanism is variable in its mode of initiation: under some circumstances every morsel swallowed is the result of conscious voluntary effort; at other times, swallowing is a reflex act, occurring independently of volition.

In studying the movements of conscious deglutition, the swallowing of solids will be considered first. As Magendie has pointed out, the act commences by a conscious and voluntary elevation of the tip of the tongue against the palate; the bolus is thus forced to the back of the mouth. The hinder parts of the tongue are then raised in succession so that the whole of the dorsum is pressed tightly against the palate. The morsel now lies at the aperture of the pharynx and the next movement is partly reflex but mainly voluntary in its initiation; by a strong and sudden contraction of the mylohyoids aided by the hyoglossi, the bolus is rapidly forced into the pharynx. The action of these muscles plays the most important part in the voluntary mechanism of swallowing. Throughout the first phase of deglutition, pressure rises inside the oral cavity, by closure of the lips and contraction of the masseters, although these muscles take no essential part in the swallowing. Falk and Kronecker [12] have computed that during deglutition the manometric pressure within the air-tight buccal cavity rises to 20 cm. of water. During forced deglutition of large boli other auxiliary movements are often associated. For example, there is frequently an accompanying movement of flexion of the head on to the neck, possibly in order to straighten out the obliquity of the fibres of the mylohyoid, which in man extend from the hyoid to the mandible diagonally upwards and forwards. The origins and insertions of the muscle are therefore approximated and the muscle is put into the optimum position for vigorous contraction. This muscle when acting elevates the hyoid in the neck, carrying with it the whole of the laryngeal box.

In order to prevent food from entering the nasopharynx a co-ordinate

movement of the tongue and palatal musculature is necessary. This act is particularly important in those animals which direct their faces downwards when taking food; man's erect posture renders it unlikely that food should travel in an anti-gravity direction into the naso-pharynx, and hence the musculature is less well developed and the velum palatæ is a less developed structure. The excommunication of the naso-pharynx from the oro-pharynx is brought about normally by pressure of the back of the tongue against the roof of the mouth, together with contraction of the levatores palatæ and the azygos uvulæ. Miller and Sherrington [20], however, have shown that in decerebrate animals in which the palate has been ablated, the back of the tongue can be pushed against the wall of the pharynx and so shut off the posterior nares. Regurgitation of food back into the mouth is prevented by the contraction of the palato-pharyngei muscles which approximate the the posterior pillars of the fauces.

An even more complex manœuvre is effected in order to prevent entry of food into the lower air passages. It was believed at one time that the epiglottis was the chief agency in guarding the laryngeal aditus, by folding down over the aperture like the lid of a box. It was later noticed, however, that removal of the epiglottis in no way affected deglutition, and the experiments of Stuart and M'Cormick disproved the hypothesis of a hinge-like action of the epiglottis, by showing that it remained erect during the act of swallowing. The protection of the air passages is brought about partly by the sphincteric action of the intrinsic muscles of the larynx; simultaneous contraction of the thyro-arytenoids, the aryepiglottici, the interarytenoideus and the thyro-epiglottidei, effectively closes the entry to the glottis by tightly approximating the vocal cords and the ventricular bands. The contraction of the interarytenoideus moreover tilts forwards the cartilages of Santorini to which many fibres of the œsophageal aponeurosis are attached. The aperture of the gullet is therefore widened in a funicular manner, at the same time as the aditus laryngis is constricted (Negus). The extreme sensitivity of the laryngeal mucous membrane is an additional safeguard, as reflex acts of violent coughing are set up when foreign particles enter the upper glottis. The air passage is also protected by an automatic cessation of respiration. This mechanism is naturally of importance in animals feeding in the erect posture, since food is liable to enter the larynx under the influence of gravity alone, unless the normal inspiratory abduction of the vocal cords is inhibited. In animals which feed in the horizontal position there is

less likelihood of the food dropping down the trachea through the separated vocal cords. Consequently we find that in some animals (e.g., dolphins and whales) simultaneous deglutition and respiration are possible.

The third stage in the act of swallowing entails the passage of the bolus from the pharynx to the stomach. Some food is probably passed from the pharynx to the gullet by successive contractions of the superior, middle, and inferior constrictor muscles, and is carried rapidly down the length of the œsophagus to the cardiac sphincter by peristaltic waves. This phase of deglutition is unconscious and automatic in execution.

The swallowing of liquids differs from that of solids in that active œsophageal peristalsis, although it occurs, is not necessary for transit through the gullet, since the middle and inferior constrictors which initiate peristalsis can be divided without interfering with the act. The liquid is rapidly shot down the upper œsophagus by the action of the mylohyoids; transit through the lower half of the gullet is slower according to Cannon and Moser [3], and the liquid is finally held up by the cardiac sphincter. This latter musculature remains closed until the wave of œsophageal peristalsis reaches the cardia. The sphincter then relaxes and allows food to enter the stomach. In man the shutting off of the glottis during drinking is further facilitated by the development of well-marked aryepiglottic folds enhanced by the cartilages of Wrisberg.

Reflex deglutition results normally from stimulation of the glossopharyngeal plexus on the posterior wall of the pharynx; in sleeping or lightly anæsthetized individuals, the presence of a bolus at the pharyngeal aditus suffices to excite reflex deglutition. During the waking state, saliva is swallowed reflexly every few minutes. Automatic acts of swallowing also take place in the early stages of anæsthetization and under emotional stress—particularly grief. They also occur when rapidly ascending to high altitudes, in order to accommodate the tension in the middle ear to the outside atmospheric pressure.

Swallowing movements associated with cessation of respiration and with change in the pulse-rate can be obtained by weak faradization of the fovea inferior of the floor of the fourth ventricle.

Speech.

In attempting to analyse the phenomenon of normal articulated speech, it is necessary to isolate the various component mechanisms and to deal with each one separately. The basis of all speech is primarily a

production of sound or phonation. This is accomplished by the passage of a current of air through a tubular organ, the lumen of which is partly obliterated by a diaphragm-like structure. The essential organ of normal phonation is therefore the lung, an apparatus capable of expelling a blast of air. The trachea and upper air passages, including the nasopharynx, act as the primitive resonating tube; the imperfect diaphragm is formed normally by the adduction of the more or less mobile thyro-arytenoid ligaments, or vocal cords. It is noteworthy that a larynx is not essential for the mechanism of phonation: complete recurrent laryngeal nerve paralysis, division of both vagi, or extirpation of the larynx, does not produce aphonia. It is common knowledge that speech of a certain character is possible in the absence of a larynx. Cases have been recorded by Czermak, Scripture [24], Burger [2], and many others. In these instances articulation was perfect; the speaking voice was rather quiet and toneless in character but normally modulated, and singing was possible even over a range of more than two octaves (from 60 to 260 vibrations per second). The bellows apparatus producing the sounds in such cases is formed by the stomach and œsophagus, the positive air pressure being brought about by deglutition (Scripture) or by inspiration; speech always takes place during the expiratory phase and therefore long sentences cannot be enunciated without the patient pausing to replenish his bellows.

The simplest component of speech therefore consists in phonation of a toneless type, and exists independently of the integrity or complexity of the larynx.

The tone of normal enunciated speech is brought about by the intervention of tautened vocal cords adducted in the route of the air stream. When no such tension and adduction occur the result is whispered phonation. In this case the laryngeal apparatus is elevated in the neck to a greater degree than in ordinary speech. Another difference between whispered speech and toneful speech lies in the fact that an individual may carry on a whispered conversation during both expiration and inspiration. For ordinary loud speech expiratory efforts are necessary, the voice at once losing tone during inspiration.

The next modification of pure phonation consists in the introduction of modulation or alterations in the pitch of the note. This is exemplified in the sounds emitted by most animals. For the production of modulated phonation, other structures are added to the simple mechanism of lung and air tube. Variations in the pitch are brought about in the simplest cases by alterations in the length and shape of

the resonating tube. These movements are executed by the depressors and elevators of the hyoid and thyroid bodies, the so-called extrinsic muscles of the larynx. In man this action of these muscles can be studied by observing the excursion of the thyroidal prominence during phonation. Notes of middle register (about 105-130 vibrations per second) can be phonated without any excursion of the pomum Adami. When notes of high vibratory rate are emitted the whole laryngeal box moves upwards in the long axis of the neck. The distance traversed by the larynx is directly proportional to the vibratory rate of the note, except for variations of extreme degree. In the phonation of very high notes other mechanisms, as we shall see, become involved. When notes of less than 100 vibrations per second are phonated, the whole laryngeal box is depressed in the neck, the excursion again depending in extent upon the vibratory rate of the note. The rôle of the extrinsic muscles in vocalization was first emphasized by Wyllie in 1886, who wrote: "The position of the larynx varies with every note."

In man, as in other creatures possessing well-developed and mobile larynges, alterations in the pitch of the note are further brought about by the agency of the intrinsic muscles of the larynx. Co-ordinate contraction and relaxation of various groups of these muscles, augmented by the action of certain of the so-called extrinsic muscles of the larynx, have the power of altering the tension of the vocal cords as they lie across the path of the blast of air; consequently, their rate of vibration varies and notes of different pitch are emitted. Thus, contraction of the cricothyroid muscles draws the cricoid cartilage upwards and backwards; the vocal cords in this way become stretched and tense. During the singing of high notes there is, therefore, in addition to an elevation of the laryngeal box as a whole, a relatively greater upward excursion of the cricoid cartilage. Furthermore, Hooper has demonstrated that the contraction of the cricothyroid muscle can be brought out reflexly by forcing blasts of air up the trachea. This is analogous to the forced expiratory effort used in singing a high note. In addition to a tightening of the vocal cords the capacity of the larynx was increased to its maximum.

The singing of low notes involves not only active relaxation of the vocal cords and depression of the larynx in the neck, but other associated or auxiliary movements as well; thus the head is usually bent a little forward on to the neck, and the neck drawn backwards. This movement possibly serves to place the depressors of the thyroid into the optimum position for contraction.

Modulated phonation as it occurs in man may, therefore, be regarded as a complex phenomenon depending partly on elevation and depression of the larynx in the neck and partly upon alteration in the tension of the vocal cords. Kenyon has computed that during vocalization the co-ordinate activity of some fifty to sixty distinct muscles is demanded, not including the muscles of the chest. The action of intrinsic and extrinsic laryngeal muscles becomes dissociated during *whispered* phonation in different keys. There is then no preparatory tension of the vocal cords; the whole mechanism depends solely upon the excursions of the larynx in the neck.

The next modification in phonation comprises the production of the various vowel sounds, which are effected by alterations in the shape of the mouth and nasopharynx. Ellis has defined a vowel sound as a "modification (due to resonance in the cavities above the larynx) of an original quality of tone, produced by the vibrations of the vocal cords in the larynx." Examination of speech records reveals that the vowel sounds are characterized graphically by various alterations in the shape of each vibratory wave due to superimposed overtones. The ability to reproduce the various vowels (other than the primitive "ah" sound) therefore entails the integrity of the muscles of the cheek and tongue.

Articulated speech depends peripherally upon the co-ordinate activity of the tongue, palatal, lower facial muscles and teeth. These structures are responsible for the production not only of the vowel sounds but also of the consonants. According to whether there is or is not any concomitant toneful voice sound, Bell divided the consonants into the voiceless (p, f, t, th, s, gh, k) and voiced (b, c, d, dh, l, v, z, zh, y, g). The consonants m, n, and ng, he regarded as voiced sounds in which a nasal element was superimposed. The central mechanism, of course, depends upon the functional activity of the hemispheres and their connections with the hypoglossal, vago-accessory and glossopharyngeal nuclei. Dysarthria, or disordered articulation, may therefore result from disease of the musculature of these parts, or from disorder of any portion of the neuronic controlling mechanism.

The quality or timbre of the voice depends both on the shape of the resonating chamber and on the mobility and amount of separation of the vocal cords. Failure of the cords to approximate during phonation produces "whispered speech." Mild disorders of their function result in a "husky" quality in the voice; defective palatal mobility produces a "nasal" quality.

The production of "falsetto" notes is probably due to certain

strands of the thyro-arytenoideus internus muscle which were proved by Bland-Sutton [25] to be inserted into the vocal cords at various places. Contraction of these fibres, referred to as the portio aryvocalis of Ludwig, breaks up the cord into two to three segments, the vibrations of which produce the characteristic falsetto voice.

Coughing.

This act can be brought about either by voluntary effort or by reflex action. In the latter case the receptive mechanism is represented by the mucous membrane of the nasopharynx, pharynx, larynx and trachea, and possibly also of some of the larger bronchi, as well as the mucous membrane of the external auditory meatus. These areas obtain their sensory innervation from the glossopharyngeal and vagal nerves.

The motor mechanism underlying coughing comprises a sudden forceful expiration of air through the opened mouth. The intrathoracic pressure is raised by contraction of the abdominal and thoracic musculature, particularly the latissimi dorsi and the recti abdominis, associated with a sphincteric closure of the glottis. When sufficient intrathoracic pressure has arisen, the sphincter abruptly relaxes, giving the typical explosive character to a cough. If the glottic sphincters are not made to participate in the act, a toneless and less forceful cough results.

Under certain pathological circumstances, as we shall see, the two phenomena of reflex and voluntary coughing may become dissociated, so that one is possible although the other cannot function.

Yawning.

This is a mechanism designed to clear out the dead space in the lungs and renew the residual air of the furthest alveoli. It can be brought about voluntarily, but it occurs more readily independently of the will under such well-known conditions as mental and physical fatigue, boredom and suggestion aroused by watching other individuals yawn. It frequently occurs shortly before the act of vomiting. In pathological cases it is sometimes met with in the form of uncontrollable bouts, such as occur after epidemic encephalitis.

The act is slow and deliberate in execution. It commences with a tautening of the elevators of the soft palate, the levator palatæ in particular. The jaws are widely opened and a prolonged inspiration occurs through a widely separated glottis; the inspiratory phase is succeeded by a prolonged expiration, often phonatory in character; this is followed by a period of expiratory apnœa. Other subconscious

movements are frequently associated with yawning, though playing no essential part in the mechanism, as screwing up of the eyes, a bracing back of the shoulder-girdles, with abduction and extension of the arms. There is also a dilatation of the pharyngeal orifice of the Eustachian tube.

As already stated, the act may be initiated voluntarily by deliberate hardening and elevation of the palate. The reflex act, though occurring independently of the will, is not altogether beyond its control, as a yawn can frequently be inhibited, in part at least. As with coughing, the two nervous mechanisms are occasionally dissociated under pathological conditions.

Humming.

This is produced in the same way as toneful phonation, except that the expiratory blast is directed through the nose instead of mouth. Escape through the buccal cavity is prevented either by compressing the lips or by elevating the back of the tongue against the soft palate. Variations in pitch are produced by alterations in position and tension of the vocal cords, together with elevation or depression of the larynx.

Laughing.

Laughter is a complex phenomenon arising normally as a physical concomitant of definite emotional states. As demonstrated by Graham Brown [1] and others, it is effected through definite psycho-facio-respiratory paths, passing from the cortex to the medullary nuclei. These pathways are completely independent of the pyramidal tract. Pyramidal activity is capable of partially inhibiting emotional laughter; it may also initiate a variety of laughter which, at the best, however. is only an imitation of the genuine act. The phenomenon is effected by expiratory blasts of air passing between vocal cords which are alternately adducted and abducted. The degree of adduction, however, does not equal that occurring during coughing. The movements of the vocal cords are accompanied by opening of the mouth and characteristic facial movements.

Crying.

As with laughter, crying is the effect of a definite emotional state, the nervous mechanism operating through cortico-bulbar pathways, distinct from the pyramidal tract. The peripheral processes comprise expiration of air through an elevated larynx; the vocal cords are tense and somewhat adducted. Spasmodic contraction of the diaphragm

leading to inspiration through still partly adducted cords constitutes sobbing. The whole phenomenon is accompanied by characteristic facial and lacrymal manifestations.

Sniffing.

Sudden inspiration of air through the nostrils constitutes sniffing. This may be carried out with the mouth open or closed. In the former case the velum is elevated, the back part of the tongue rises, shutting off the pharynx from mouth. At the same time there is a general depression of the whole laryngeal box in the neck. When the mouth is closed by compressing the lips, the tongue remains immobile during sniffing. The velum however rises, and the depression of the larynx occurs as before.

Blowing of Nose.

Sudden expiration of air through the nostrils associated with a depression of the velum palatæ constitutes nose blowing. If this act is carried on when the mouth is open, the back of the tongue is raised in close apposition against the soft palate. Expiration of air through the mouth is thus prevented.

Structure and Functions of the Larynx.

It is clear that whilst the larynx takes no essential part in the mechanism of articulation proper, it plays an important rôle in the modulation of phonation, and in the production of a loud and characteristic timbre to the voice. It is important to realize, however, that phonation is only one of several important functions subserved by the larynx, a structure which we believe originated for a completely different purpose. The integrity of the larynx can be shown to assist materially such diverse functions as respiration, olfaction, and deglutition, besides being one of the chief regulators of the intrathoracic pressure. Much of our knowledge of the comparative anatomy and physiology of the larynx we owe to Edgeworth [10, 11], Frazer [13], and Negus [22, 23].

Negus [23] and others have shown that a larynx first appears in the dipnoi or lung-fishes as a sphincteric muscle band guarding the aperture to the air tract. Its function was to prevent the entry of food or water into the primitive trachea. Higher in the evolutionary scale dilator fibres appear, and find attachment to small cartilaginous structures which constitute the primitive arytenoid and cricoid cartilages. Later, a thyroid cartilage develops from the fourth visceral

arch and a membranous fold connects this with the cricoid body; part of this fold forms the primitive vocal cord. The whole of this structure constitutes a larynx whose function is primarily that of protection of the air tract against foreign substances.

Later on, the larynx takes on other functions; for this reason further anatomical modifications occur, and there develop from the pharynx those structures which we recognize as the epiglottis, the ary-epiglottic folds and the supporting cartilages. These new functions will be dealt with later.

In the human embryo of 5 mm. two distinct sets of cells arranged around the larynx and pharynx are apparent: an inner ring derived entirely from the fifth arch which later forms all the intrinsic muscles of the larynx, and an outer ring derived from the fourth arch, which afterwards forms the cricothyroids, the stylopharyngei and the constrictors of the pharynx. In the fourth-month fœtus it is still impossible to differentiate between the constrictors and the cricothyroids.

Returning to the inner ring of cells it is possible, even at two months, to distinguish well-marked crico-arytenoidei postici, and inter-arytenoidei; the thyro-arytenoidei and crico-arytenoidei laterales cannot yet be recognized. Hence in the human embryo, as in the phylogenetic scale, the adductor components of the laryngeal musculature develop before the abductor elements. In the next two months of development, the individual muscles become more differentiated and the direction of their fibres alters. These changes are due, firstly to the upward growth of the thyroid cartilage in the neck, and secondly to the development of arytenoid cartilages.

In man the larynx is in some respects a degenerate structure, and differs from the larynx of other animals in the diminutive size of the cartilages of Wrisberg and the smallness of the appendix ventriculi. Certain modifications in the fibre arrangement of the thyro-arytenoideus internus muscle, particularly respecting the appearance of a vocalis muscle, are characteristic of the human larynx. Lastly, the vocal cord itself is distinguished in man by the breadth of the interval between the muscle tissue and the free edge of the plica; this interval is occupied by elastic fibres (Duckworth [8]). (See fig. 1.)

The various functions of the larynx other than those concerned with speech will be considered individually.

(*a*) *Olfaction.*—Some animals (as certain of the reptiles) whose existence depends to a great degree upon their highly developed olfactory sense, possess the ability to smell whilst actually chewing or eating.

This is due to the development of a large and highly organized epiglottis which has the power of keeping separate the olfactory and respiratory air tracts. In man this function is of a very minor importance and we consequently find a small and relatively immobile epiglottis.

(*b*) *Respiration.*—During ordinary quiet breathing the vocal cords are separated because of a condition of active tonus in the abductor

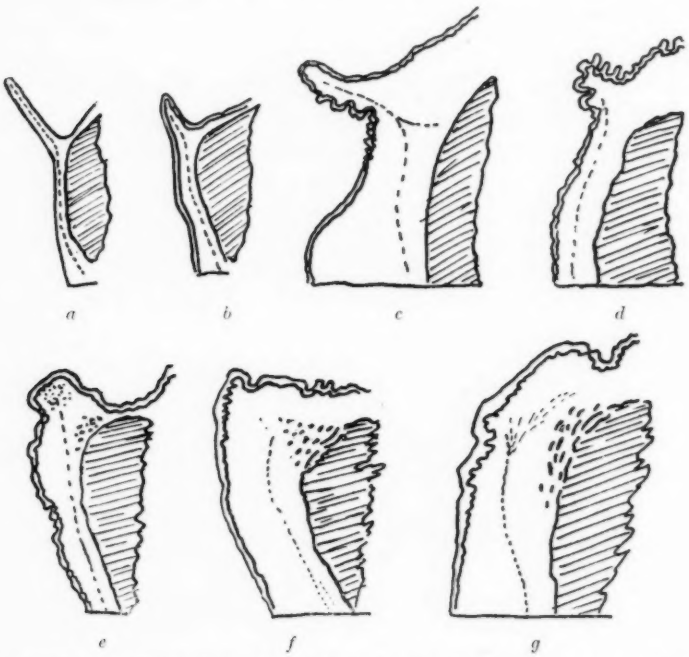


FIG. 1.—Diagram illustrating variations in the comparative anatomy of the vocal cords:—(*a*) Cebus; (*b*) macacus; (*c*) gorilla; (*d*) chimpanzee; (*e*) aboriginal Australian native; (*f*) negroid Hindu of Assam; (*g*) European. (After Duckworth.)

muscles, the crico-arytenoidei in particular. After death, or after division of the two vagi, some degree of approximation is seen, proving that the abduction is due to a state of active tonus. The adductors of the vocal cords are not primarily muscles of respiration, but act as accessory muscles during forced or excited breathing. Under such circumstances the glottis opens widely during inspiration and shuts almost completely during expiration, owing to alternate activity of abductors and adductors. The adductor group of muscles also participates in the

modified forms of respiration due to psycho-motor activity, such as laughing, crying and coughing. In cases of extreme dyspnœa other extraneous muscles take part, especially the stylopharyngeus, the pharyngeal constrictors, the sternohyoid, thyrohyoid, sternothyroid and cricohyoid.

Negus [23] has demonstrated that the size of the glottic aperture and the direction of the air-stream from mouth to lungs varies in the animal scale with the speed of progression. Thus in the swift-running ungulates the oral and nasal passages are in the same straight line as the trachea and larynx, when the head and neck are extended as in flight. Again, in such animals the glottic aditus is comparatively greater in diameter than in the slower moving animals. These structural modifications are obviously contrivances for ensuring a sufficient oxygenation of the blood by an adequate air supply.

(*c*) *Deglutition.*—The separation of the air and food passages during swallowing, as already mentioned, is the prime function of the adductor components of the primitive larynx. In the human larynx the sphincteric closure of the glottis is effected by means of the combined action of the crico-arytenoidei laterales and postici, together with the arytenoidei obliqui and transversi.

(*d*) *Regulation of the intrathoracic pressure.*—During hard muscular exertion, during straining or bearing down, the glottis is closed, usually at the height of the inspiratory phase, and the intrathoracic and intra-abdominal pressures rise by reason of contraction of the trunk muscles. This mechanism cannot operate unless the glottic sphincter is made to contract forcefully. By this means not only do the vocal cords come together like the flaps of a valve, but the plicæ ventriculares are also approximated. Negus has collected evidence which suggests that this function has developed in the animal scale parallel with the prehensibility of the fore-limbs, the mobility of the upper ribs and the appearance of upper thoracic respiration.

Functions of the Velum Palatæ.

In man the two main functions of the soft palate assist in phonation and deglutition. The velum palatæ elevates during phonation and partially shuts off the nasopharynx from the expired air, except during the enunciation of the nasals *m* and *n*. Failure of the palate to rise results in a peculiar nasal intonation to the speech, and also to a distinct "blowing" character. These speech changes are frequently evanescent, altering with changes in posture; examination of the pharynx

may reveal no defect of mobility or of reflex elevation, even though the speech is distinctly nasal. This timbre is therefore a very delicate indication of impaired palatal function.

The palate also rises during mouth breathing, rising during the early stages of both inspiration and expiration. During deglutition there is an involuntary elevation in order to shut off the posterior nares from the passage of any foodstuff. The participation of the palate in such acts as sniffing, nose blowing, and yawning has already been referred to. Lastly, by the contraction of the levator palatæ, the pharyngeal orifice of the Eustachian tube is opened and hence regulation of the air pressure in the middle ear is one of the functions of the palate. Contraction of this muscle cannot be directly brought about by a voluntary effort, but is effected automatically by voluntary deglutition.

Functions of the Tongue.

The main functions subserved by the tongue are primarily those of deglutition. The high-grade development and mobility of this organ in animals who are completely silent is of course a commonplace. In many animals, particularly in those whose fore-limbs are purely locomotory in function, the tongue acts as a prehensile organ, picking up solids and liquids and carrying them to the oropharynx. In certain carnivora, monkeys and other mammals, in which the fore-paws are prehensile, the tongue is used for conveying fluids only to the pharynx, solids being carried to the mouth by the paws. In man the tongue possesses but very slight prehensibility outside the oral cavity. The morsel of food is transferred from the fore part of the mouth to the pharyngeal aperture by an orderly contraction, first of the intrinsic muscles and then by the hyoglossus.

The tongue also acts in conjunction with the orbicularis oris during many physiological actions. Thus, in the act of sniffing the lips normally prevent air from entering via the mouth; if the lips are paralysed or are allowed to remain apart, the back of the tongue is automatically raised against the soft palate in order to prevent air entry. The same phenomenon is observed during expiration of air through the nose. The tip of the tongue, acting in conjunction with the lip muscles, takes part in the act of expectoration.

The tongue is an important factor in the mechanism of articulation and is responsible for the correct enunciation of the lingual consonants (*d*,*t*,*l*,*r*). It also assists in the production of the nasals (*m* and *n* and *ng*) by shutting off the buccal cavity from the air-stream. In cases in

which the larynx has been removed, the tongue also acts as an organ of phonation. In such cases, a pseudoglottis is formed by an elevation of the posterior part of the tongue against the palate. The tongue also plays an extremely important rôle in normal speech in determining the tone and quality of the sounds.

The sensation of taste, mainly localized in the epithelium of the tongue, has been shown by Miller and Sherrington [20] to be in some measure a protective function. Thus in decerebrate cats drops of water, saliva or weak alcohol placed upon the hinder part of the tongue provoked a ready swallow response. When castor oil, weak solutions of caustic soda, or acetic acid were placed in the glosso-epiglottic sinuses, diglutition did not occur. Solutions of quinine and colocynth were swallowed at first, but after a few trials reapplications to the tongue evoked retching and vomiting.

Kidd [17] has drawn attention to an association in movement between the protruded tongue and the muscles supplied by the homolateral ansa hypoglossi. If a finger is placed on the neck below the cricoid cartilage, just medial to the sternomastoid muscle, a contraction of the sternohyoid and sternothyroid is felt on the side to which the tongue is deviated. Another instance of movement association, referred to by one of us [4 and 5], is voluntary lateral deviation of the eyes associated with an unconscious movement of the tongue towards the homolateral side. This phenomenon was observed in a large number of normal individuals.

Chapter II.—Personal Cases.

With the object of obtaining information as to the factors responsible for the dysphagia and dysarthria of bulbar palsy, a series of patients was studied with especial reference to the laryngeal and pharyngeal functions. Of these patients, five died and came to autopsy. The central and peripheral nervous systems were examined in these cases, and the individual muscles of the tongue, palate, pharynx and larynx, studied histologically. To these five cases, we were able to add a sixth through the kindness of Dr. Gordon Holmes. The same sets of muscles were isolated and examined in a control case.

The clinical notes of the cases which were examined histologically will first be recapitulated, after which the pathological changes in the muscles will be discussed.

Case 1.—L. H., a female, aged 58, was admitted to hospital July 23, 1925, under Dr. Gordon Holmes.

She was unable to give an account of her illness because of complete anarthria and inability to write. We were told by a friend that her illness began eighteen months previously with weakness of the legs and a disturbance of speech. She had been bedridden for a year; the power of speech was completely lost seven or eight months before admission.

Examination disclosed a patient with all the signs of advanced progressive muscular atrophy with bulbar involvement. Breathing was laboured and noisy, and was performed entirely by the diaphragm and cervical muscles. The heart, lungs, and abdomen were healthy.

The corneal reflexes were present; there were bilateral, symmetrical weakness and wasting of the muscles of mastication, and weakness of the facial muscles including the orbiculares oculorum and frontalis. She was scarcely able to move the angles of the mouth, and could not pout the lips, whistle, or inflate the cheeks. The palate did not move on phonation and the pharyngeal reflex was absent. There was extreme wasting of both sternomastoids and trapezii; there was an atrophic, fibrillating tongue devoid of all voluntary movement. Otherwise the cranial nerves were normal.

In the motor system there were bilateral *main en griffe* and extreme wasting, weakness and fibrillation of the muscles of upper and lower extremities, more advanced distally than proximally. Tone was increased. The intercostal muscles were paralysed and wasted, and the abdominal and trunk muscles were also greatly affected. Sensation was normal.

The jaw-jerk was active; the tendon-jerks of arms and legs were very brisk; there was ankle clonus on both sides: both plantar responses were extensor in type; there was no sphincter disturbance.

The urine, blood and cerebrospinal fluid were normal; the Wassermann reaction was negative in the blood and cerebrospinal fluid.

Bulbar manifestations.—The patient had complete anarthria; phonation was limited to an inarticulate sound, midway between "ah" and "eh." She was unable to alter the pitch, which was a little higher than the speech of an average woman.

At the height of her dyspnœa, there was marked expiratory stridor, which often continued without intermission for several hours, despite all therapeutic measures. It was present during sleep as well as in the waking state. She gave us to understand that this was not an expression of pain but that it was an involuntary and uncontrollable phenomenon. She was unable to swallow either solids or liquids; semi-solids were swallowed with very much difficulty.

During inspiration the larynx moved upwards a $\frac{1}{2}$ in., and when swallowing $1\frac{1}{2}$ in. By laryngoscopic examination the vocal cords were seen to separate during inspiration; they fell together at the beginning of expiration, separated slightly immediately afterwards, and remained so during the remainder of expiration. They appeared to be loose and gave the impression of "flapping" during expiration.

There was little variation of any significance in the clinical manifestations between the time of her admission and death, which occurred eighteen months after the onset of her illness.

Case 2.—M. S., a female, aged 57, was admitted on September, 21, 1925, under Dr. Gordon Holmes. The history was obtained from her husband.

Her present illness began in September, 1923, with slight speech difficulty. In February, 1924, she began to have difficulty in swallowing solids. Her legs became weak in June, 1924, and the arms in January, 1925. From that time the bulbar symptoms and the weakness of the arms and legs progressed more rapidly. She had been bedridden and practically anarthric for three or four months, but could still write with difficulty. Swallowing of both liquids and solids had become difficult.

Examination revealed the characteristic features of amyotrophic lateral sclerosis with advanced bulbar involvement. No abnormality was found in the heart, lungs or abdominal organs.

There was a brisk jaw-jerk and weakness of all the muscles of mastication. The upper and lower facial muscles were much affected. There were inability to close the lips, elevate the corners of the mouth, wrinkle the brow, or voluntarily to close the eyes, although there was infrequent blinking of the eyelids and the corneal reflexes were brisk. There was an active pharyngeal reflex, but the palate did not move on phonation. The sterno-mastoids and trapezii were moderately wasted and almost completely paralysed. The tongue, in which fibrillation was present, was small and could not be moved in any direction. The cranial nerves were otherwise normal.

There were bilateral *main en griffe*, marked wasting, fibrillation, and almost complete paralysis of trunk and extremities; the tone was greatly increased. Sensation was normal.

The tendon-jerks in arms and legs were brisk; the abdominal reflexes were absent; the plantar responses were extensor in type; there was no sphincter disturbance.

Bulbar manifestations.—There was complete anarthria. Phonation was limited to an inarticulate sound, midway between "ah" and "eh," the pitch of which could not be varied. Humming was impossible even when the lips were held shut by the examiner. During phonation the larynx rose $\frac{3}{4}$ in.

There was dysphagia for both liquids and solids, which increased while the patient was under observation. Soft solids could be swallowed more easily. She was unable to swallow to command. During deglutition the larynx ascended a distance of $1\frac{1}{2}$ in. The mylohyoids contracted with a fair degree of strength. Nasal regurgitation was never present.

Voluntary efforts at coughing resulted in a mere forced expiration of air. Reflex coughing, though weak, was definitely explosive in character; obviously there had been a previous closure of the glottis. Straining was impossible and enemata were necessary to move the bowels. Laryngoscopy was impossible, because of reflex irritability of the pharynx.

The symptoms gradually progressed and the patient died from respiratory failure on November 15, 1925, two years and two months after the onset of her illness.

Case 3.—A. H., a female, aged 55, was admitted on January 1, 1925, under Dr. Gordon Holmes.

Two years prior to admission she began to drag the left leg when walking. Both legs became weak and wasted, and "fluttering" was felt in the muscles. Seven months later weakness of the left arm with wasting and "fluttering" of the muscles was noted, and a month later the right arm was similarly affected. Ten months after the onset of symptoms she observed difficulty in swallowing and disturbance of speech. The dysphagia progressed until solids could not be swallowed at all and liquids could be taken only through a straw.

Examination disclosed a patient with the characteristic features of amyotrophic lateral sclerosis with bulbar involvement. The heart, lungs, and viscera were healthy.

Glycosuria was present constantly whilst the patient was in hospital. The resting blood-sugar was 0·22 per cent.; the cerebrospinal fluid was normal and the Wassermann reaction was negative in the blood and cerebrospinal fluid.

The corneal reflexes were normal; the muscles of mastication were moderately affected. There was bilateral weakness of the upper and lower facial muscles. The lips could be closed, though whistling and inflation of the cheeks were impossible. The palatal movement on phonation was norma and there was an active pharyngeal reflex. Nasal regurgitation was not present at any time. The sterno-mastoids and trapezii were considerably wasted. There was a small fibrillating tongue which could be protruded only 1 cm. beyond the teeth. Otherwise the cranial nerves were normal.

There were typical deformities of the hands, and marked wasting, spasticity and fibrillation of the muscles of the trunk and extremities, with almost complete paralysis. The intercostals were almost immobile; the diaphragm moved slightly. The sterno-mastoids contracted visibly during inspiration. Sensation was unimpaired.

The tendon-jerks in the arms and legs were weak; the abdominal reflexes were absent and a plantar response was not obtained on either side.

Bulbar manifestations.—There was almost complete anarthria, which later became complete although the ability to make inarticulate sounds was never lost.

She was unable to swallow solids or semi-solids; fluids could be swallowed with difficulty by drinking very slowly through a straw or tube.

She was unable to strain at stool.

Laryngoscopical examination was impossible because of a brisk pharyngeal reflex and salivation.

Her condition gradually became worse, and she died twenty-seven days after admission.

Case 4.—T. F., a male, aged 42, was admitted March 10, 1924, under Dr Hinds Howell. The family history was negative and his previous health had always been good.

His illness began four months previously; weakness of the right leg and right arm was followed a month later by difficulty in speech and a few days after this by difficulty in swallowing solid food. At the time of admission he was able to walk only with assistance. Swallowing of liquids as well as solids had become very difficult.

Examination disclosed an emaciated patient whose appearance was characteristic of advanced progressive muscular atrophy. Respiration was very much embarrassed; the intercostal muscles and diaphragm acted scarcely at all and the accessory muscles of respiration stood out prominently during inspiration. There were wasting and fibrillation of the muscles of the upper extremities and of the intercostal muscles, with weakness and slight wasting of the leg muscles. The right side was affected considerably more than the left. Sensation was normal. A jaw-jerk was not obtained; the tendon-jerks were present in the arms but absent in the legs; the abdominal reflexes were weak; both plantar reflexes were flexor in type.

The corneal reflexes were present. There were marked wasting and weakness of the muscles of mastication on both sides, and bilateral weakness of the upper and lower facial muscles, the latter being considerably more affected. The patient could close the lips but could not whistle or inflate the cheeks. The palate moved well on phonation; nasal regurgitation did not occur at any time. Both sterno-mastoids were very much wasted. There was but little wasting of the upper trapezii. The tongue was small, fibrillating and very imperfectly protruded. Otherwise the cranial nerves were normal.

Bulbar manifestations.—Analysis of speech was difficult because of the respiratory disturbances. It was sufficiently intelligible for a short history to be given. The chief difficulty was with the labial and lingual consonants. Solids could not be swallowed at all while fluids could be taken only with the greatest difficulty.

Laryngoscopic examination was not attempted because of the severe dyspnœa.

The patient died from respiratory failure on March 14, 1924, four and a half months after the onset of his illness.

Case 5.—R. N., a male, aged 27, was admitted July 23, 1923, under Dr. James Taylor.

Eighteen months previously he had observed muscular weakness and wasting beginning in the hands which gradually involved the arms, followed by weakness, wasting and spasticity of the legs. Dysarthria and dysphagia had been present for three months. On examination nothing abnormal was found in the heart, lungs, or abdominal organs.

Both corneal reflexes were present: there was weakness of the muscles of mastication. The orbiculares oculorum were weak and the forehead could be wrinkled only slightly; whistling was impossible and the cheeks could be inflated only to a slight degree. The palate moved well on phonation, and the pharyngeal reflex was present. Nasal regurgitation did not occur at any time. The sterno-mastoids were moderately wasted and very weak, so that

the head was raised from the pillow with some difficulty. The tongue was only moderately atrophied and could be protruded fairly well; fibrillation was present. The cranial nerves were otherwise normal.

Bulbar manifestations.—Except for a nasal quality, speech was, as a whole, fairly good when the patient was admitted. Before the patient's death speech became very indistinct, although not quite unintelligible to anyone familiar with it.

Dysphagia, though present, was not a prominent symptom at any time.

Laryngoscopic examination by Mr. Just showed that the vocal cords acted normally during phonation and respiration.

Death from respiratory failure occurred on June 29, 1923, two years after the first symptoms were observed.

Case 6.—This case was one of the series investigated by Dr. Gordon Holmes [15] in his study of the pathology of amyotrophic lateral sclerosis. We are indebted to him for a description of the changes in the central nervous system, including the condition of the bulbar nuclei, and for histological sections of the laryngeal muscles prepared by him at that time.

The patient, a female, aged 53, was admitted January 1, 1906, under Dr. James Taylor. There had been progressive loss of power in the limbs for two years, and difficulty in articulation and swallowing for six months.

On examination the fifth cranial nerves were normal; the orbiculares oculorum were strong; retraction of the lips was feeble. The palate moved fairly well though there was regurgitation of food through the nose. The tongue was wasted, contracted laterally, and could not be protruded past the lips.

There were "claw hands"; the muscles of the extremities were wasted, very weak and spastic. The trunk muscles were weak. Sensation was normal.

There was exaggeration of all the tendon-jerks, with absent abdominal reflexes and extensor plantar responses. Sphincter control was impaired.

Bulbar manifestations.—There was almost complete anarthria and very marked dysphagia, particularly for fluids; although palatal movement was good there was regurgitation of food through the nose.

While the patient was under observation all of the facial muscles became involved. Complete anarthria was observed before death, which occurred on July 25, 1906, two and a half years after the onset of symptoms.

Chapter III.—Pathology.

The clinical diagnosis of amyotrophic lateral sclerosis was confirmed in each case by histological examination. The changes in the central nervous system were characteristic, viz., degeneration of the ventro-lateral columns of the cord, most pronounced in the areas occupied by the pyramidal tracts, degeneration of the motor centres of the spinal

cord and bulb, and degeneration of the pyramids in their course from the cortex to the cord. The posterior columns were little if at all affected.

In five of our cases the vagal nuclei were examined by Nissl's method. In each case there was well-marked evidence of disease of the nucleus ambiguus. The cells were much reduced in number; those that remained stained less deeply than healthy cells in the same section; some were so pale as to be scarcely visible. They were rounded in outline and the nuclei were indistinct and eccentric in position. In all of the cells there was complete or almost complete disintegration of the tigroid substance, which when present was situated at the periphery of the cell. Practically all of the cells contained large amounts of lipochrome pigment; a few were almost completely filled with it.

The changes in the dorsal vagal nuclei were not marked. There was little if any loss of cells. Definite degenerative changes, limited to the mesial and ventral parts of the nucleus, were present in two of the cases; the lateral group of cells was normal in every case.

The changes described by Holmes in Case 6 were essentially the same: " . . . . some loss of cells in the nucleus ambiguus and chromatolysis in many of those which remain, but no recognizable change in the dorsal vagal nucleus."

Various descriptions of the condition of the vagal nuclei in amyotrophic lateral sclerosis have been given. In Holmes's group of cases [15], and in two cases described by Marinesco [19], the nucleus ambiguus was diseased, whilst the dorsal nucleus was unaffected. Oppenheim stated that the vago-accessory nucleus is usually diseased, and that changes in the nucleus ambiguus had been found by himself and others. Mundie [21] reported a case in which the dorsal nuclei were definitely affected, though to a lesser degree than the ambigui. Kronthal [18] has described a case in which the dorsal nucleus alone was affected. Tooth and Turner [26] found no change in any of the vagal nuclei in a case with severe dysarthria and dysphagia, and in which paresis of the abductors and tensors of the larynx had been demonstrated during life.

Although there is a difference of opinion concerning the functions of the vagal nuclei it is generally believed that the nucleus ambiguus supplies the muscles of the larynx and that the dorsal nucleus has a sensory and sympathico-motor function. Support is given to the view that the nucleus ambiguus supplies striped muscle by the almost constant finding of extensive degeneration of its cells in a disease

which affects chiefly the somato-motor components of the nervous system.

Before dealing with the changes in the laryngeal muscles, we shall

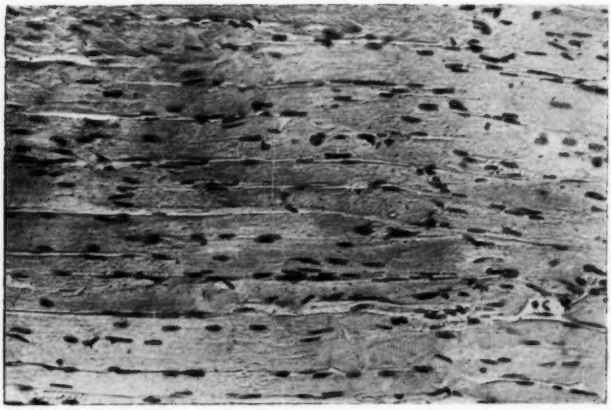
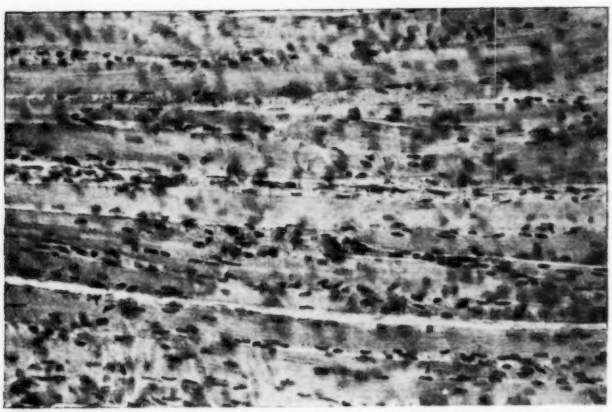


FIG. 2.—M. inter-arytenoideus; normal case.



FIG, 3.—M. inter-arytenoideus from Case 5.

endeavour to give a brief description of the histological appearances of simple muscle atrophy.

Of the numerous contributions to this subject the investigations of Hayem [14] and of Durante [9] have been particularly valuable.

As Durante pointed out in 1902, muscle atrophy resulting from various diseases of the lower motor neurone is characterized by essentially similar histological findings. He called this "simple atrophy" or

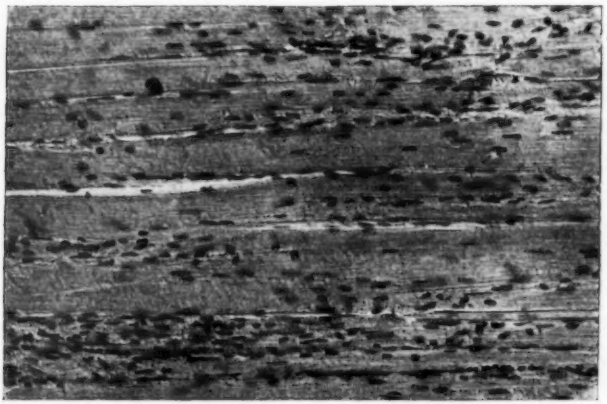


FIG. 4.— M. inter-arytenoideus from Case 4.

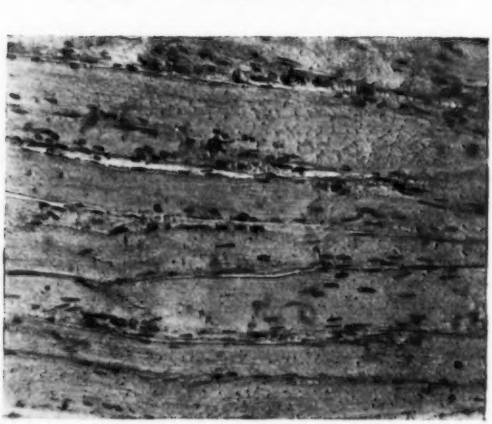


FIG. 5.—M. crico-arytenoideus posticus; normal case.

"*atrophie par régression cellulaire*," in contradistinction to degenerative changes such as hyaline, fatty, or pigmentary degeneration which may occur in toxic, cachectic, or vascular disorders, apart from involvement of the nervous system, the best example of which is the condition described by Zenker as occurring in typhoid fever.

Since degeneration of muscle frequently occurs in diseases which do not affect the nervous system it is obvious that only structural changes in the cellular elements can have any significance in the study of muscle

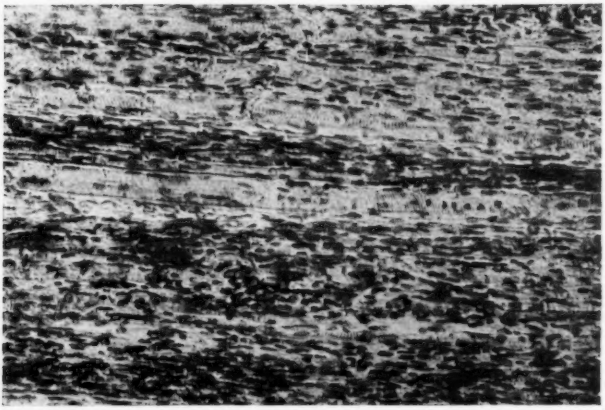


FIG. 6.—M. crico-arytenoideus posticus from Case 5.

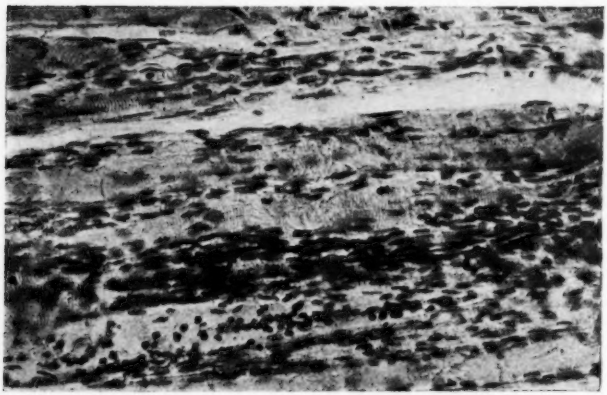


FIG. 7.—M. crico-arytenoideus posticus from Case 4.

atrophy, particularly if there is associated toxæmia, cachexia, vascular disease, or any other systemic process.

In simple atrophy resulting from destructive lesions of the peripheral nerves, or from disease or destruction of the motor centres of the spinal

cord or bulb, the earliest change consists in an increase in the number of the sarcolemma nuclei. It has been suggested that an actual proliferation of nuclei does not occur since definite mitotic changes have

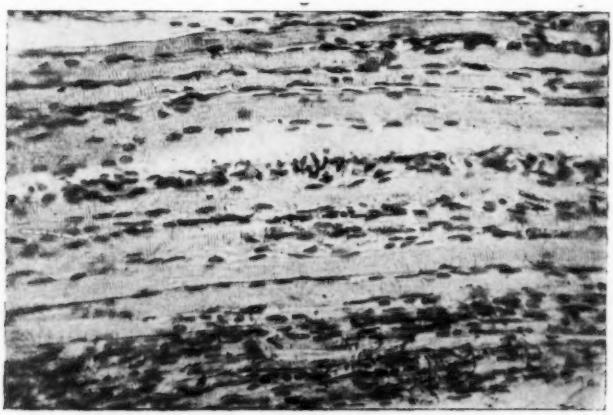


FIG. 8.—M. crico-arytenoideus posticus from Case 3.

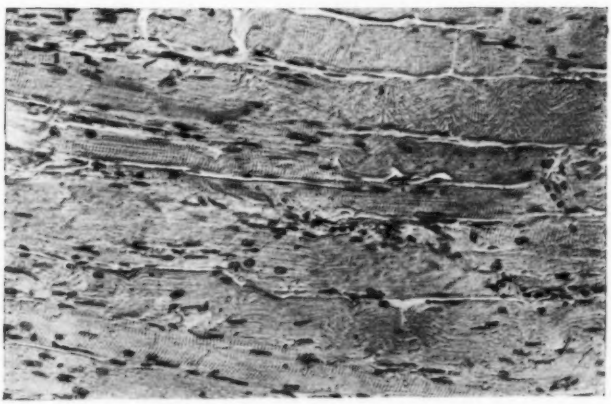


FIG. 9.—M. thyro-arytenoideus internus; normal case.

not been found, and that there is only an apparent increase due to shrinkage of the muscle fibre. This supposition would scarcely account for the chains of small, round nuclei, which are so commonly found and which are, according to Durante, the result of nuclear division.

In the simple atrophies central nuclei have not been seen by us in sections taken at right angles to the directions of the fibres. If the fibres were cut a little obliquely some of the nuclei appeared to be centrally situated, but by focusing they could be shown to lie below the surface of the section, probably in contact with the underlying sarcolemma.

Some investigators describe a swelling or increase in the size of the muscle fibres. It is a well-established fact that enormously large fibres may be found in the myopathies. However, in simple atrophy of various muscles resulting from peripheral nerve lesions and in anterior-poliomyelitis as well as in amyotrophic lateral sclerosis, large fibres have

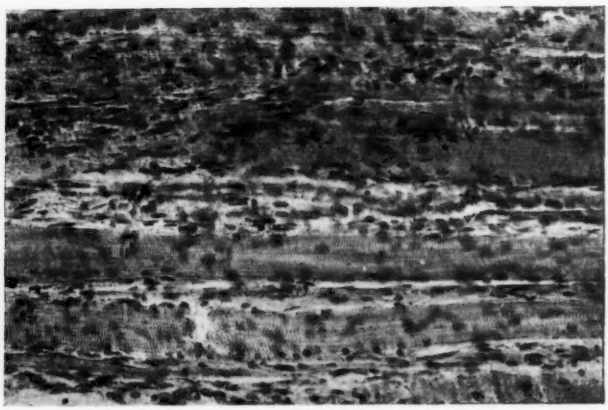


FIG. 10.—M. thyro-arytenoideus internus from Case 4.

been seen by us only rarely. Since similar fibres are often found in sections of normal muscle we have not attached any significance to them. It is possible that they are due to post-mortem trauma or the process of fixation.

As atrophy advances small fibres containing many nuclei are to be seen. At least some of these small fibres are formed by the longitudinal division of a larger fibre. Thus a fibre of normal size may be seen to divide into two, three or possibly more small fibres, in which further subdivision occurs. It is probable that most, possibly all, of the smaller fibres originate in this way. At the same time a diminution in size through loss of substance is probably taking place in all of the fibres.

The fibres continue to decrease in diameter, the myoplasm disappears, and there is left only a strand of sarcolemma barely large enough to accommodate the nuclei which are arranged in more or less compact chains within it. Until this stage has been reached the cross striations are visible with proper magnification and illumination, and are found to extend quite to the sarcolemmal sheath. Not infrequently the cross striations in normal muscle removed some hours after death and examined in the usual way are very indistinct. We, therefore, believe that variations in the cross striations in the absence of more definite structural changes cannot be considered an evidence of atrophy.

Although the observation has been made that the longitudinal

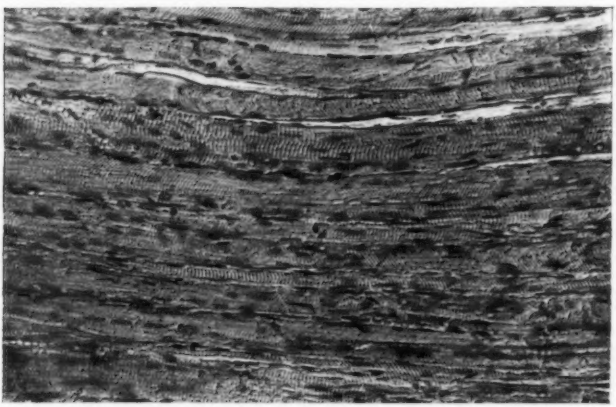


FIG. 11.—M. crico-arytenoideus lateralis from Case 4.

striations are more distinct we have been unable to satisfy ourselves that they differ in any way from the normal.

Occasionally, poorly stained areas resembling vacuoles, ranging in size from that of a nucleus to one-third of the cut surface of the fibre, were seen in the centres of the muscle fibres.

Later there is an increase in the interstitial connective tissue between the muscle bundles; there is relatively little increase between the individual fibres. Finally, the sarcolemma and nuclei disappear as well as the myoplasm, and are replaced by connective tissue or by connective tissue and fat. In specimens examined by us a recognizable increase in the amount of connective tissue was a rather late finding. An excess of interstitial fat and the presence of fat cells in the muscle

bundles were observed in atrophy resulting from peripheral nerve lesions, but were never seen in amyotrophic lateral sclerosis.

The histological changes which have been described take place very slowly. Dr. Greenfield has kindly placed at our disposal sections made

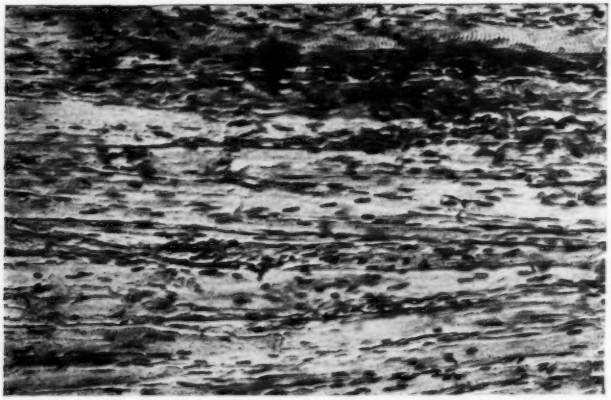


FIG. 12.—M. crico-thyroideus from Case 5.

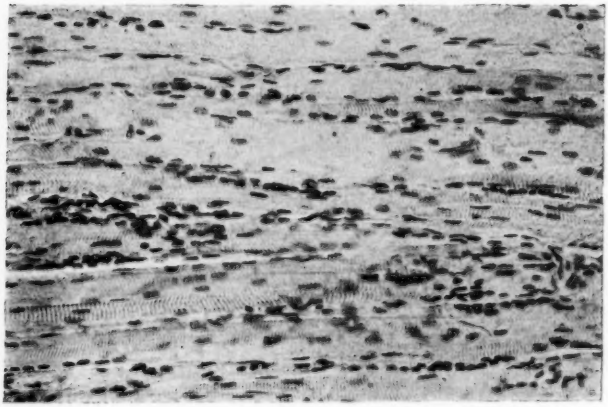


FIG. 13.—Middle constrictor of the pharynx from Case 3.

by him in the course of experimental work on animals, and others from a human subject who sustained a complete lesion of the ulnar nerve three months before death. In the human case there was an increase in the number of sarcolemma nuclei; all of the muscle fibres were small,

ranging in size from a half to two-thirds of the normal; the cross striations were distinct and the connective tissue between the muscle-bundles was slightly increased in amount. Fat cells were not present in the muscle bundles or in the interstitial tissue. In the experimental cases atrophy progressed a little more rapidly, so that from thirty to sixty days after nerve section it equalled in intensity that of the human case ninety days after the injury.

In amyotrophic lateral sclerosis the complete or practically complete atrophy of muscle which sometimes results from peripheral nerve lesions was not observed; even those muscles which had been completely paralysed for a number of months and appeared clinically to be very much wasted were found, on dissection, to possess a certain, sometimes a surprisingly large, amount of muscle tissue.

Histological examination revealed that many of the fibres were only moderately affected. The appearance was more patchy than in atrophy following complete peripheral nerve lesions. In the same histological section there was usually atrophy of varying intensity, ranging from a moderate increase in the nuclei of otherwise practically normal fibres to almost complete atrophy of others; small fibres in which cross-striations were not visible and fibres of normal size were frequently found lying side by side.

Dejerine observed, in 1883, that the atrophy of the tongue in a case of bulbar palsy was not as pronounced as clinical appearances would have led one to expect. In our experience the same disproportion between the apparent degree of wasting and actual atrophy exists in the case of other muscles as well, and may be due to a loss of fat.

The disparity between paralysis and atrophy may be explained partly by the fact that there is also disease of the upper motor neurones which accounts for much of the loss of function, and partly by other factors. Thus the duration of amyotrophic lateral sclerosis is almost always less than two and a half years; the nerve cells die slowly and not all of the cells supplying a muscle are destroyed at the same time, so that when death of the patient occurs some of them, though undergoing degeneration, are still alive. Therefore muscle atrophy, never a rapid process, takes place more slowly than usual, and the muscle fibres which are supplied by comparatively healthy nerve cells are but little affected. Consequently when death occurs atrophy is incomplete, frequently only moderately advanced, and unevenly distributed throughout the muscle.

The following table sets out graphically the relative extent of histo-

logical change in the muscles of the cases examined. According to the degree of atrophy, the muscles have been relegated into three groups, indicated by a single, double or triple plus signs.

TABLE I.

	Case 1.		Case 2		Case 3		Case 4		Case 5		Case 6
	R.	L.	R.	L.	R.	L.	R.	L.	R.	L.	
TONGUE—											
Intrinsic	+++	..	..	..	+++	..	+++	..	+++	..	+++
Extrinsic:											
Genioglossus	..	..	++	++	..	..	++	++½	++½	..	..
Hyoglossus	..	++	++	++	++	++	++½	+	+	..	++
Styloglossus	..	..	+	+½	+	..	..	+	..	..	..
SUPRAHYOID—											
Mylohyoid	..	++	++	++	..	++	++½	+++	+	+½	+++
Geniohyoid	..	..	++½	++½	..	+½	+++	+++	+	+½	
Digastric (anterior belly)	+½	..	++	++	++	..	..	..	+	+	
Stylohyoid	..	..	++	++	..	..	..	..	+	..	..
INFRAHYOID—											
Sternohyoid	+	..	++	++	+½	++	..	..	..	..	+
Sternothyroid	+½	..	+½	..	+½	++½	..	..	..	..	
Thyrohyoid	½	..	++	++	++	++	+	..	..	..	
Omohyoid	+	+½	++	++	++	++	..	..	..	..	..
Extrinsic laryngeal—											
Cricothyroid	..	+	+½	+½	..	+	++	++	+++	+++	..
INTRINSIC LARYNGEAL—											
Crico-arytenoideus posticus	..	++½	++½	+++	..	+++	+++	+++	+++	+++	+++
Crico-arytenoideus lateralis	..	+	++	++	..	+	+++	+++	..	..	
Thyro-arytenoideus	..	+½	++	+++	..	+++	+	+½	+++	++½	
Interarytenoideus	..	+	++½	..	..	+	..	++	++	..	
PALATAL—											
Tensor palati	..	..	+	..	..	..	..	..	++½	..	..
Levator palati	..	..	+	..	..	..	..	..		..	..
Palato-pharyngeus	+½	..	..	+	..	..	..	..	++	..	..
CONSTRICTORS OF PHARYNX—											
Superior	+	..	..	..	+	..	..	..	+	..	+
Middle	+	..	..	..	..	..	+	..	+	..	
Inferior	++	..	+½	..	++½	..	+	..	..	..	

CHAPTER IV.—MORBID PHYSIOLOGY IN BULBAR PALSY.

The microscopical examination of the muscles subserving speech and deglutition in six cases of progressive bulbar palsy demonstrated, firstly, that no part of the musculature was exempt. Every muscle that has been examined gave evidence of atrophic change, but not to the same degree; the relative involvement is shown in Table I. In every case the intrinsic musculature of the tongue was severely affected; there

is evidence, clinical as well as histological, to suggest that the changes had commenced in the tip of the tongue and advanced from before backwards. Those portions underlying the mucous membrane presented more change than the deeper parts. The intrinsic muscles of the larynx also showed very definite and extensive atrophy, almost equal in degree to that in the tongue. The constrictors of the pharynx, as emphasized by Collier, were but little changed; in some cases there was nothing that could be considered incompatible with normal; it appeared, moreover, that the inferior constrictor was more affected than the superior, the middle constrictor occupying an intermediate position. The elevators and depressors of the larynx also showed definite atrophic signs, but less severe than the intrinsic laryngeal musculature. The suprahyoid muscles showed an amount of change equal to that of the subhyoid group, though in each case examined the changes in the mylohyoid muscles were of outstanding degree. The palatal muscles showed very definite pathological change in the two instances in which they were examined.

Histology of the cervical muscles gave no evidence of an asymmetrical march to the disease; unlike the extremities, the internal and external laryngeal muscles presented a bilateral and approximately equal extent of morbid change. In the tongue, however, it is not unusual for the atrophy to appear first on one side, and to remain unilateral over a considerable period.

Emphasis must be laid upon the limitations of a pathological study of laryngo-pharyngeal involvement in progressive bulbar palsy. Little or no information results from a comparison of the relative degree of atrophic change in particular muscles. It must be borne in mind that amyotrophic lateral sclerosis is a disease of the upper neurons as well as of the lower neurons. Examination of the muscles indicates the amount of involvement of the latter system only. A particular muscle or movement may be almost abolished by reason of loss of its pyramidal control, and yet histological study of the muscle in question will reveal no abnormality unless it happens that the corresponding lower motor system is also affected. Dejerine, forty-two years ago, remarked that the degree of myatrophy is slighter on histological examination than might be expected clinically. Some cases of bulbar palsy remain spastic from start to finish, and go on to the stage of complete anarthria and profound dysphagia with scarcely any atrophy of the muscles.

It follows, therefore, that the absence of morbid change in a section of muscle does not indicate that the muscle was functioning normally

during life; the presence of definite atrophic manifestations, however, is always an indication of impaired function.

Inspection of the neck in cases of bulbar palsy usually reveals characteristic features. The head tends to be retracted, because of the relative preponderance of the post-vertebral muscles. The outline of the neck is distorted by atrophy of the subcutaneous fatty tissue and of the sterno-cleido-mastoid and subhyoid muscles. When there is weak-

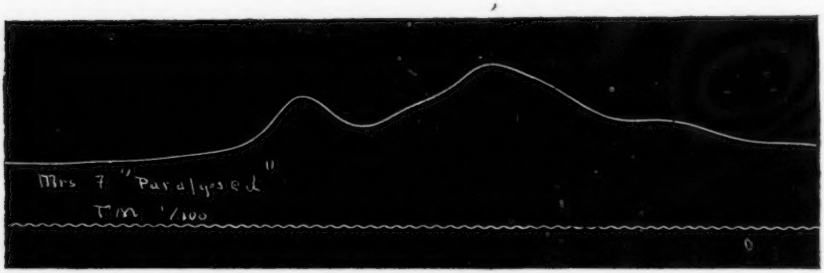


FIG. 14.—Graphic record of a bulbar patient's attempts to say "paralysed." There is an absence of the finer modulations of normal speech; the elevation of the curve is due to the expiratory blast accompanying the vocal effort. Note the great reduction in the amplitude of the fine vibratory waves.

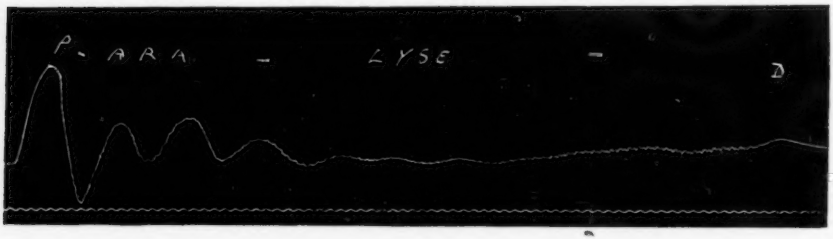


FIG. 15.—Graphic record of normal speech. The explosiveness of the labial (*P*) and dental (*D*) is very well illustrated. The fine vibratory waves correspond with the vibrations of the vocal cords during phonation of the vowels. The curve shows clearly the modulations of normal speech.

ness of the anterior bellies of the omohyoids the outline of the muscle cannot be demonstrated by making the patient flex his head against resistance. The platysma in these cases stands out prominently over the underlying atrophied muscles in many diagonal and vertical folds, which are sometimes observed to fibrillate. In some instances the larynx is dropped in the neck so that the cricoid cartilage lies only a quarter to half an inch above the suprasternal notch; this is due to the

greater degree of wasting in the suprahyoid than in the subhyoid muscles. In most cases it is possible to obtain a reflex contraction of any of the muscles by a sharp tap, demonstrating the extreme hyperexcitability of the atrophic musculature.

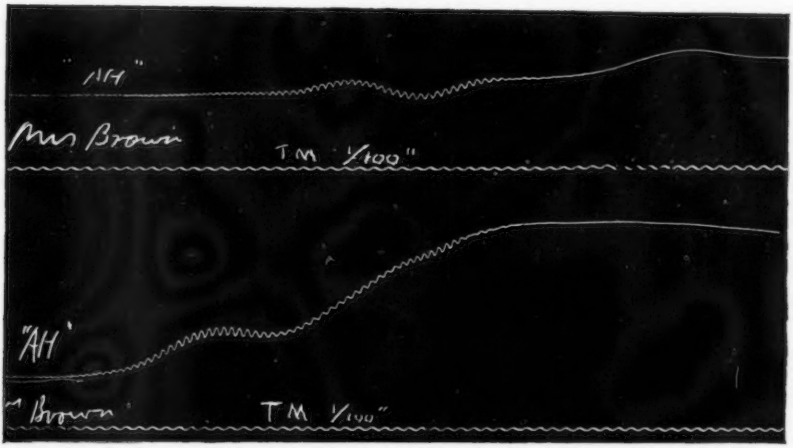


FIG. 16.—Graphic representation of phonation of the sound "*AH*" by a patient with bulbar palsy. The lower curve shows the explosive expiratory effort. In each instance the patient was directed to maintain the sound as long as possible.
Note the very ready fatigability of the voice.

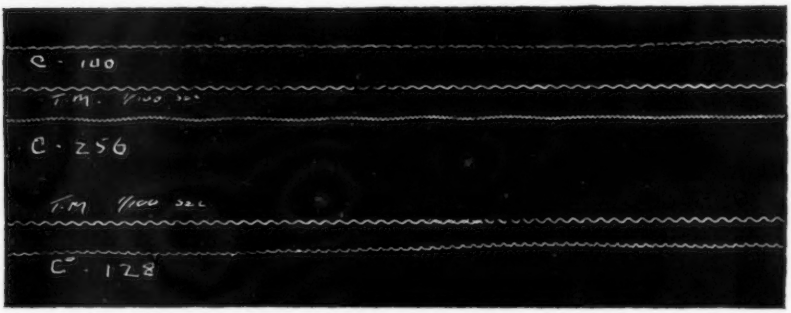


FIG. 17.—Normal records of phonation in varying keys. The sound "*AH*" is emitted in each case, but the pitch of the note is different.

In discussing the mechanism of speech as it applies to cases of bulbar paralysis, the subject first needs to be considered from a purely clinical aspect. The earliest signs of speech disorder usually pass

unnoticed by the patient himself although apparent to his associates. In most cases, a distinct though slight nasal timbre is the first evidence of disorder. This nasality is not constant; it is accentuated when the patient speaks loudly or quickly, or attempts to sing high notes, but tends to disappear during quiet deliberate articulation. In other instances the first evidence of speech difficulty is noticed on singing; the patient himself will often remark that his compass has become limited, so that he is no longer able to sing as high or as loud a note as formerly.

Later some difficulty appears in the articulation of certain consonants, particularly labials (*p*, *b*) and linguals (*l*, *r*). When the patient becomes aware of this defect he frequently attempts to correct it by speaking with great slowness and deliberation. At the same time the nasal quality of the voice becomes more noticeable and singing is almost impossible.

At a later stage, articulation of all consonants becomes difficult. The dental sounds, *d* and *t*, become defective; later still the guttural sounds are poor. The nasal sounds, *m* and *n*, frequently remain fairly good until very late stages, though they are definitely "blowing" in character. Vowel sounds are usually unaffected at this stage. The range of the voice undergoes a further restriction, so that eventually any alteration in the pitch becomes impossible. Not only does singing therefore become quite out of the question but the speaking voice also loses its finer modulations—the so-called *chanson de parler*.

The final stage is one of complete anarthria; vowels as well as consonants cannot be enunciated; there never is aphonia, however; not only can sound still be emitted from the throat, but this sound has a loud timbre, possessing none of the qualities of whispered speech. The only sound possible at this stage is harsh in character, intermediate between an "ah" and an "ee," the pitch of which cannot be varied. It has a peculiar strained quality as though the patient were in pain, and cannot be sustained for more than one or two seconds. It lacks, moreover, the explosiveness which occurs normally at the commencement of the sound "ah." The charts in fig. 16 illustrate graphically the only sound possible in one of these anarthric patients.

The absence of modulation in the speech is due to the same factors which are responsible for the limitation in range of the singing voice, namely, disease of the elevators and depressors of the larynx or of the intrinsic musculature, or of both. Some additional information on this point can be gleaned from laryngoscopic examination of the vocal cords

during life. This is frequently a very difficult matter on account of the reflex hyperexcitability of the soft palate. When it is possible it is usual to find only slight alteration in the appearance and motility of the cords. In early cases it is the rule for the cords to move normally on respiration and phonation. In more advanced cases the cords are less tense and move less briskly; on phonation they tend not to come together in close approximation, but to remain very slightly abducted.

TABLE II.

Case	Sex	Age	Bulbar symptoms	Condition of vocal cords
F. P. ..	M.	49	Dysphagia Great dysarthria	"Normal larynx; both cords move well"
E. S. ..	M.	37	No dysphagia Severe dysarthria	"Both arytenoids and vocal cords move normally"
L. H...	F.	58	Great dysphagia Anarthria Stridor	"Cords separate during inspiration; they are approximated at the commencement of inspiration, but separate slightly immediately afterwards"
L. B. ..	F.	55	Severe dysphagia Anarthria	"Cords widely separated; approximate during attempts at phonation"
M. F...	F.	34	Dysphagia Dysarthria	"Ventricular bands prominent; vocal cords both move but do not completely approximate upon phonation. They do not come together completely upon adduction"
G. R. ..	M.	45	Dysphagia Dysarthria	"Move well on respiration and phonation"
R. N...	M.	27	Dysphagia Dysarthria	"Both cords move normally on inspiration and phonation"
W. M...	M.	71	Dysphagia Anarthria	"Both cords move normally"

The well-known Rosenbach-Semon's law, which emphasizes the earlier implication of the abductor group of muscles in recurrent laryngeal nerve palsy, has not been investigated fully for nuclear and supranuclear lesions of the laryngeal nerves. Semon has stated that this rule also applies to the nuclear affections of the larynx occurring in tabes dorsalis. This observation has been confirmed by Burger. We have been able to find but few references to the laryngoscopic appearances of the vocal cords in cases of progressive bulbar palsy.

Tooth and Turner [26] studied histologically the medulla of a patient with bulbar palsy whose cords during life were said by Semon himself to have been in a state of bilateral abductor paresis. The glottis did not open any wider than 3 mm. on inspiration, whilst a

small oblong gap appeared between the cords on phonation. Collier [6] stated that in his series of cases of bulbar palsy there was no obvious defect in the movements or position of the vocal cords, except in one instance where laryngoscopy revealed a marked bilateral abductor paralysis.

In our present series of cases we could find no evidence that the adductor muscle groups were affected later or to a lesser degree than the abductors. In both sets of muscles the pathological process was approximately equal. In Table II the results of laryngoscopic examination are given of a number of cases of bulbar palsy recently observed.

The morbid physiology of the progressive anarthria can only be explained by a steadily advancing affection of all the muscle elements of speech, comprising both the intrinsic and extrinsic laryngeal muscles and the muscles of lips, tongue and palate.

When the earliest manifestation consists in the imposition of a nasal component to the speech, it is evident that the palatal musculature is affected. At this stage, however, there is no defect in the mobility of the palate, either on phonation or respiration or on reflex stimulation. There is, moreover, no defect in the sphincteric action of the palate during drinking, and regurgitation of fluids does not occur. This nasal timbre is therefore the earliest and most delicate criterion of slight palatal involvement.

Two factors are responsible for the early difficulty in singing notes of high pitch. There may be a defect in the intrinsic musculature of the larynx so that defective adduction and abduction of the vocal cords result; the thyro-arytenoideus internus muscles (aryvocales) in particular may by reason of very slight defect give rise to difficulty in registering high notes. On the other hand the difficulty may be due to the defective mobility of the larynx as a whole up and down the neck—resulting from disordered function of the supra- and sub-hyoid muscles. It is probable that these two conditions co-exist and are at fault.

The inability to articulate is the result of involvement of lips and tongue. Clinical experience shows that guttural sounds can be produced long after the dentals are lost. This observation coincides with clinical and pathological findings in demonstrating that the morbid process commences in the tip of the organ. Hence, defective articulation of dentals will precede the difficulty in swallowing hard objects and the disordered articulation of gutturals.

The ability of the patient to sing falsetto notes is lost very early in

cases of bulbar palsy. This is due to implication of the cricothyroid muscle so that the vocal cords lose their tension, together with atrophy of the "aryvocalis" fibres of the internal thyro-arytenoid muscle. Whispered articulation and modulated whispering are lost early, though pure "ah" sounds of middle register can still be whispered.

In the early stages weakness of the orbicularis oris does not prevent the patient from humming if an associated elevation of the back of the tongue can be effected. When this organ is also affected humming becomes impossible, as the buccal cavity can no longer be shut off from the oropharynx. Sniffing also becomes impossible when lips and hinder part of the tongue are both affected. Implication of both tongue and palate renders it impossible for the patient to blow his nose. In many cases a difficulty in expectoration is one of the first manifestations of bulbar disease. Since this performance depends upon the integrity of the lips and the tip of the tongue—structures which are affected early in the disease—this symptom is not difficult to comprehend.

Some patients on being questioned stated that they were unable to yawn. If this observation is correct, it may be presumed to result from inability to tense and elevate the palate and to separate the faucial pillars. It must be remembered at the same time that there is weakness of the trunk muscles which of course play an important part in the act of yawning.

Both laughing and crying are executed by patients with bulbar palsy, but the character of the sounds is distinctly altered. There is a lack of modulation and a complete absence of the explosive character typical of normal crying and laughter. In most patients, especially those in whom the pyramidal lesion predominates, there is a very definite instability in emotional expression, together with a loss of self-control. Consequently there is marked exaggeration in the temperamental affect, with occasional spontaneity of laughter and weeping. In one of our patients this feature was so pronounced that she dislocated her jaw twice in one day as a result of some trivial upset. Some patients present many of the features of the so-called "pseudo-bulbar palsy" and the differential diagnosis is not always evident. Another feature can sometimes be demonstrated, namely, the inability of the patient to initiate a laugh, although he laughs normally upon appropriate emotional stimuli. This phenomenon exemplifies the frequent dissociation of voluntary and emotional movements in the domain of the psycho-facio-respiratory mechanism.

Coughing, as we have seen, necessitates a firm closure of the glottic sphincter, followed by an abrupt relaxation. This phenomenon is lost in those cases with marked atrophy of the intrinsic muscles of the larynx. The patient's attempts at coughing assume a peculiar harsh and braying character, lacking the toneful and explosive nature of normal coughing. The expiratory phase is frequently succeeded by inspiratory stridor, suggesting defective abduction of the vocal cords during forced respiratory efforts. The inability to execute a forceful cough exposes the patient to the danger of aspiration pneumonia.

In many patients, particularly in those with the spastic type of bulbar affections, a feature of the utmost interest may often be detected. The patient is completely unable to initiate a cough at command, showing that the volitional corticospinal pathway, namely, the pyramidal tract, is defunct. The patient, however, emits a reflex cough almost naturally upon stimulation of the normal receptive areas. Such a phenomenon, frequently met with in the so-called "pseudo-bulbar palsy," indicates that there is not so much atrophy of the intrinsic musculature of the larynx as paralysis due to disease of the upper neuron.

Amongst the bulbar symptoms some slight difficulty in swallowing is frequently the first complaint of the patient himself. In most cases, however, his associates have detected before this some change in the speech. Emphasis has been laid by some upon the character of the dysphagia in the early changes in progressive bulbar palsy; thus, liquids re sometimes said to be the source of greatest difficulty whilst othera authorities speak of early dysphagia for hard solids. Careful inquiry along this line suggests that there is no rule in these cases; approximately half of the patients complain first of difficulty in drinking whilst the other half state that hard morsels present the greater difficulty.

In the later stages the character of the dysphagia becomes more obvious. There is a constant difficulty in the deglutition of liquids; dysphagia for hard boli is not quite so marked as for liquids, whilst there is much less difficulty in swallowing soft pultaceous material.

The act of drinking is executed in a very characteristic fashion. The head is thrown far back because the atrophic tongue is unable to force back the liquid. In some patients (e.g., Case 3) drinking is facilitated by sucking fluid up through a straw. The mouthful is then swallowed in a series of small forced gulps which entail considerable effort. Fluids frequently escape forwards through the wasted lips and through the

angles of the mouth. Regurgitation through the nose is uncommon, however. There is a great tendency for some of the liquid to enter the air passages and, as the sensibility of the glottis is intact, a great deal of choking or coughing is set up. In more advanced cases the protective cough mechanism ceases to function and hence the air tract loses another of its defences. During the actual gulping down of the liquid the hyoid and thyroid rise in the neck over a considerably greater excursion than normal. Often the elevation is as great as 1½ to 2 in.

In the case of solids the maximum effort is required to force the food through the faucial pillars into the oropharynx. Small morsels may linger in the mouth for fifteen to twenty minutes. There is often an exaggerated flexion movement of the head on to the chest, the whole act obviously being one entailing much voluntary effort. When questioned, the patient usually refers the site of apparent obstruction to the region of the cricoid cartilage.

When examined under a fluoroscopic screen, the patient shows very clearly all these features when attempting to swallow an opaque meal. The bolus is retained in the mouth for a considerable period, often many minutes. The tongue is powerless to force the bolus to the back of the mouth, and the patient performs all manner of extraneous movements in his effort to swallow—throwing his head far back, flexing it well on to the chest, or actually pushing the bolus with his finger into the pharynx. As soon as the morsel has passed the posterior faucial pillars swallowing proceeds with normal speed and facility. It is perfectly evident that there is no loss of function of the œsophageal musculature during the act of deglutition.

The morbid physiology of this type of dysphagia can be explained by weakness of the lips and tongue, and in particular by implication of the mylohyoid muscle. This muscle by its contraction is the chief factor in propelling hard morsels and fluids through the pharynx; thick fluids tend to find their own way down the pharynx without forceful propulsion from the muscles of the floor of the mouth. Weakness of the glottic sphincters is of course responsible for entry of fluid into the larynx; weakness of the palato-pharyngeus causes feeble contraction of the post-pillars of the fauces; food is therefore liable to regurgitate into the mouth and to escape past the atrophied orbicularis oris. Defective elevation of the soft palate would theoretically result in nasal regurgitation of fluids during deglutition, but as a matter of clinical experience such a phenomenon is rare. This is probably due to the wasting of the tongue and lip muscles preventing the rise of intrabuccal pressure.

The resulting tension is insufficient to force fluid in an antigravity direction past the paresed velum into the choanæ.

Although morbid changes of slight degree are sometimes met with in the constrictor muscles of the pharynx, it is highly improbable that implication of these structures plays any part in the dysphagia. X-ray examination confirms what might be inferred from the whole nature of the disease, namely, the exemption of unstriped muscle; consequently, the passage of food down the œsophagus is normal.

As in the case of coughing, the phenomena of reflex and voluntary deglutition are sometimes dissociated. Thus, movements of reflex swallowing are often possible, even though the patient is unable to initiate the movement at will. This again may be explained by disease of the supranuclear controlling mechanism with relatively less affection of the lower neuron.

The problem of dysarthria and dysphagia may now be approached from a different angle, and consideration given to the clinical phenomena resulting from disease of the nerves or muscles of various anatomical entities. As we have seen, the larynx participates in many physiological acts besides phonation, and each of these functions may become disorganized.

The effects of paralysis of the intrinsic musculature may be summarized briefly. Sphincteric closure of the glottis is extremely feeble, so that, firstly, during deglutition particles of food tend to enter the air passages. Secondly, it becomes impossible for the patient to execute a forceful cough at will; however, in certain cases in which the pyramidal pathway suffers more than the lower neuron, the power of voluntary coughing alone is lost whilst a reflex cough can still be elicited. At a later stage, when atrophy of the muscles themselves sets in, this reflex cough also disappears. Thirdly, toneful laughter and sobbing also become impossible, as these acts necessitate a rhythmical contraction of the adductor elements of the vocal cords. A fourth consequence of disease of the intrinsic laryngeal muscles is the inability of the patient to strain or bear down, since it is impossible for the patient to raise the intra-abdominal pressure. Straining at stool and passage of flatus therefore become impossible; the power of lifting is diminished not only because of affection of the skeletal muscles, but also because of this inability to fix the chest.

It is very uncommon for dyspnœa to arise as a result of laryngeal paralysis, except in those exceptional cases in which the vocal cords become adducted because of symmetrical abductor palsy.

The chief vocal effects of intrinsic laryngeal atrophy may be briefly recapitulated: (1) The voice loses first its full compass and its power of registering falsetto notes; (2) the normal inflexions and modulations of vocalization are lost and speech assumes a monotonous character; (3) the clear timbre of normal speech is marred by harsh and raucous overtones. Complete aphonia, however, does not occur.

Paralysis of the extrinsic laryngeal muscles (elevators and depressors of the hyoid) occasions difficulty in speech, in deglutition and in respiration. The speech affection comprises difficulty in singing high and low notes and inability to whisper. There is moreover very definite difficulty in swallowing, especially hard boli and liquids. Deglutition is a function of the mylohyoids in particular, and we suggest that atrophy or spasticity of this muscle is responsible for the major part of the dysphagia in this disease. The subhyoid group of muscles also act as accessory muscles of respiration; paralysis of these muscles, when associated with paralysis of the intercostals and recti abdominis, predispose the patient to a death from respiratory failure.

The effects of palatal implication in this disease are briefly: (1) A nasal and blowing quality to the speech; this is the earliest evidence of palatal involvement; (2) regurgitation of fluids through the nose: a rare phenomenon in this disease owing to the low intrabuccal pressure; (3) inability to yawn; the power of voluntary yawning is usually lost before the disappearance of reflex yawning; (4) inability to sniff, hum, or to blow the nose. Objectively one may observe a defect or absence of palatal elevation and an alteration in the character of the pharyngeal reflex. In the more spastic cases the reflex is exaggerated, rendering laryngoscopy very difficult. When the degree of pyramidal involvement is very slight compared with the degree of atrophy, the reflex may be lost.

The effects of involvement of the tongue are manifold. Thus, there is a great difficulty encountered in conveying the bolus of food from the fore part of the mouth to the anterior pillars of the fauces. This difficulty is overcome in many cases by tilting the head far back so that the food passes by gravity into the back of the mouth.

Immobility of the tongue is responsible for much of the dysarthria, particularly in the pronunciation of linguals. The alteration in the quality of phonation is also in part due to spastic or atrophic paralysis of the tongue. The power of expectoration is lost early in most cases, since implication of the lips and tip of tongue are usually amongst the first of the bulbar manifestations.

In a few patients in whom lateral deviation of the tongue was impossible, attempts at this act resulted in an associated contraction of the sternohyoid and sternothyroid and anterior belly of the omohyoid muscles, although no movement whatever of the tongue was visible. On the contrary, an involuntary deviation of the tongue associated with lateral ocular movements was never observed.

We beg to tender our thanks to Drs. James Taylor, Gordon Holmes, and Hinds Howell for their kindness in allowing us to make use of their cases. We should like furthermore to express our gratitude to Dr. Greenfield for his untiring interest and assistance in this work.

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VARICELLA-MYELITIS.

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Acute myelitis may be caused by different acute infectious diseases due to specific viruses, as typhoid fever, measles, scarlet fever, &c.

Cases have been described after chicken-pox, although most writers suggest that varicella-myelitis is very rare. On the other hand the relation of chicken-pox to diseases of the nervous system has become a matter of interest during the last few years, since it has been observed that it is not rare to find herpes zoster associated with chicken-pox; herpes may even be seen alternating with varicella in the course of an epidemic.

Only very few cases of varicella-myelitis have been published in the literature. I am therefore describing a case which has come to my notice.

P. C., a boy aged 8, was admitted into the department for nervous diseases of the Kommunehospital in Copenhagen, on February 25, 1925.

The patient had previously been in good health; there was no history of any injury to his back. On February 9, 1925, he had an eruption of chicken-pox, but was a rather slight case as his temperature did not rise above 38° C. He remained in bed until February 19; when he got up on this day he could hardly walk and complained of attacks of pains in the left thigh. After a couple of days he again tried to walk, but he was unable to do so, and he still complained of pains irradiating down to his foot.

On February 24 he felt pains in his abdomen and arms. A pediatric specialist examined him and found the patient slightly febrile; there was some stiffness of his neck, sighing and a marked change of colour. When he tried to walk his gait was ataxic, and his knee-jerks were very brisk. The following night he was restless, had severe vomiting, and greater stiffness of his neck; the next day a complete paralysis of the lower extremities had developed, with loss of the knee-jerks.

On admission to the hospital there was nothing abnormal in the functions of the cranial nerves or of the upper extremities, apart from an anisocoria, the right pupil being larger than the left. There was marked stiffness of his

neck. On the trunk there were small crusts and red scars, the remains of the chicken-pox rash.

The bladder was felt some centimetres above the pubis. When the patient tried to raise his head there was no contraction of the abdominal muscles. The abdominal reflexes were absent. There was hyperæsthesia and analgesia of the trunk below a transverse line through the nipples.

In the lower extremity there was free mobility of the joints and the tone of the muscles was diminished. The knee-jerks and ankle-jerks were absent. Babinski's sign was present on both sides, with a complete "réflexe des raccourcisseurs." The whole of the lower limbs were hypæsthetic and analgesic. The urine contained albumin.

The cerebrospinal fluid contained 37 cells per c.mm., 40 albumin and 2-3 globulin. (Method of Ross-Jones and Bisgaard.)

The Wassermann reaction was negative in the cerebrospinal fluid. The blood serum gave a negative Wassermann reaction with heart extract, a feeble positive reaction with syphilitic antigen, and a Σ-positive reaction (these last two reactions may not be considered as specific). Five days later a lumbar puncture was again done and the fluid contained now 24 cells and 15 to 18 albumin. Cultures from the cerebrospinal fluid (Dr. Vilh. Jensen) yielded a few colonies of *Staphylococcus aureus*, but these may have been an artificial contamination from the skin.

The patient improved gradually. His temperature, which had been 37·9° C. at first, became normal. There was retention of urine for the first days, then incontinence of urine for about ten days, when micturition became absolutely normal. The stiffness of the neck disappeared in a short time. The tone of the muscles of the lower extremities increased.

Five days after admission a feeble knee-jerk could be obtained on the right side and some days later on the left, and from this time the tendon-reflexes became more and more active. A week after admission active movement of the lower extremities reappeared, the power increased and the affection of sensation diminished in intensity. On March 24 the analgesia had completely disappeared and only a very feeble degree of tactile hypæsthesia remained, its upper limit being 8 cm. below the nipples. The abdominal muscles contracted well and the lower limbs could be moved with moderate strength; the patient could stand and move his legs a little when he was supported by two nurses. There was some ataxia in their movements. The tone of the muscles was slightly increased. The knee-jerks were very active, there was patellar clonus on both sides and ankle-clonus on the right, but the left ankle-jerk was feeble without clonus. Babinski's sign was present on both sides. Slight myoclonic contractions of the muscles of the lower extremities were sometimes observed. From this time on he made steady progress; on April 2 he could walk without support, with only slight ataxia and a little spasticity of the lower limbs. His gait improved, and when the patient was discharged from the hospital on April 13 he was completely cured; his gait was natural, the disturbances of sensation had entirely disappeared and the tendon-jerks and the plantar reflexes were quite normal.

The patient was treated during the first twelve days with hexamethylene-tetramine. Eight days after admission passive movements of the ankle-jerks were instituted to prevent equinus contracture. Fourteen days later a night bandage was prescribed, and a month after admission massage of the lower limbs was started.

There is little doubt that this was a case of myelitis caused by chicken-pox and probably produced by the varicella virus itself. It is improbable it was due to a secondary infection, although this possibility cannot be absolutely excluded. The favourable course of the disease agrees with the good prognosis of chicken-pox.

In studying the literature I have been able to find a few cases only of varicella-myelitis. One of these was very similar to my own and I will therefore mention it in detail.

Wharton Smith described in 1916 the following case: A boy aged 7 years was admitted on August 17, 1914, to the dispensary of the Harriet Lane Home (Baltimore). On June 1 he had developed an ordinary attack of chicken-pox. On June 14 the fever increased and his mother noticed that his legs and his left arm were paralysed. Very severe sensory disturbances were present in his legs, more marked in the left. In a fortnight, sensation had become normal and he could use his left arm, but his legs remained paralysed. Some days later retention of the urine set in, and later on incontinence of urine and fæces which lasted for six or seven weeks.

Examination on August 19 showed: Knees flexed and rigid, legs slightly atrophic. Knee-jerks exaggerated, especially the right. Paresis of both lower limbs. Cutaneous reaction for tuberculosis positive, Wassermann reaction negative. On September 4 the child was discharged much improved. On October 2 he was again examined; he could walk with some difficulty, but his knees were somewhat flexed. The tendon reflexes were exaggerated and Babinski's sign was present.

On August 5, 1915, there was a marked improvement; he could play freely, but a little spasticity of the legs remained, the reflexes were exaggerated and Babinski's sign was present.

This case shows a development of the disease somewhat like my case, but the recovery was not so complete.

Marfan described in 1893 a case of spinal paralysis following varicella in a child aged 9 months, but this case was complicated by the presence of otitis, tuberculosis and gastro-intestinal dyspepsia.

Rossi recorded in 1903 a case of flaccid paralysis of the right arm in a boy of 11 months, which developed with the onset of the chicken-pox rash. It is possible that the palsy in this case was of spinal origin, but the author considered it was more probably peripheral.

Other cases are described in the literature which were regarded by the authors as polyneuritis, or peripheral paralysis following varicella.

William Gay published in 1894 the case of a child aged 2 years and 5 months. Six and a half weeks before the patient was first seen, chicken-pox of moderate severity developed. He was found one morning, a fortnight after the onset of the varicella, to be completely paralysed in his lower limbs. A doctor found that he could stick a pin into the soles of his feet without producing any pain. The arms could be moved. For three weeks the paralysis remained complete, the child apparently making no effort to move his lower extremities, which remained extended on the bed flaccid and motionless. Nine days later he made his first attempt to walk, and two days later he was brought to hospital. His gait was decidedly ataxic, although there was a considerable amount of shuffling of the toes owing to the greater degree of paralysis of the extensor muscles. A large amount of sensory disturbance was undoubtedly present in the legs. The knee-jerks and plantar reflexes were absent. The author regarded this as a case of peripheral palsy. It is possible, but the possibility that it was a myelitis must be considered.

Allaire described (1905) a case which he considered to be a peripheral neuritis, but which was most probably a myelitis or encephalo-myelitis. A boy, aged 8, developed a paralysis of his left arm following an attack of varicella; at the same time his voice became nasal and fluids regurgitated through his nose. After two months the palsy of the arm was still marked and a slight atrophy of the muscles appeared. The nerves of the arm were tender. Electric examination showed the reaction of degeneration. After some months the paralysis disappeared.

Camus and Sézary published in 1907 the case of a girl, aged 11, who had at the age of 6 developed chicken-pox; three days after the eruption appeared contractures of the legs and later atrophies of the muscles occurred. Some time later similar symptoms developed in the upper extremities, with violent pains and tenderness of the muscles. These pains disappeared again, but the atrophy and some paresis remained for five years. On examination sensation to touch was normal, but there was hyperæsthesia for pain. The tendon reflexes were also absent. The authors regarded the case as one of a polyneuritis, possibly combined with an interstitial myositis.

Stuchlik has also observed a case of so-called polyneuritis after varicella and measles. There was a flaccid paralysis of the lower limbs which later involved the whole body and the throat muscles; it is, however, possible that the palsy may have been due to measles.

In addition to these cases of myelitis, or possible myelitis, one can find in the literature a series of cases of encephalitis or encephalitis-like affections following chicken-pox. Marfan described in 1898 external ophthalmoplegia, and Chavernac in 1908 optic neuritis; Rocaz and Lartigout (1921), Sterling (1918), Caccia (1904) and Miller-Davidson (1914), have published cases in which they diagnosed encephalitis; Menko, in 1899, described choreiform symptoms, and Bouvy (1898) a case called multiple sclerosis, or encephalo-myelitis. Osler has seen hemiplegia after chicken-pox, and finally, Koplik, De Toni, Lenoble and Thielemans and Soffia have observed cases of meningitis following this disease.

On the whole it seems that affections of the central nervous system after chicken-pox are very rare in proportion to the great frequency of this disease, but they cannot be regarded as purely accidental. The good prognosis as regards myelitis following varicella corresponds with the usually favourable course of the original disease.

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Syndromes neuro-anémiques. Par PIERRE MATHIEU. Pp. 172. Paris: Gaston Doin. 1925. Price 20 francs.

The little attention that subacute combined degeneration of the spinal cord has received in French neurological literature has been attributed to the rarity of this disease in France, and there is still evidence that it occurs there less frequently than in Great Britain and certain parts of the United States. Mathieu in fact has been able to see only ten cases in the hospitals of Paris, but it is possible that many cases escape detection.

This monograph is a straightforward account of the clinical and pathological features of the spinal disease, and in these respects it adds nothing to our knowledge. There is, however, an interesting reference to polyneuritis occurring in the course of pernicious anæmia. Degenerative changes in the peripheral nerves have, of course, been frequently discovered in subacute combined degeneration, and many experienced clinicians have observed cases in which the symptoms and signs suggested disease limited to the peripheral nervous system. Mathieu attempts to focus attention on these cases and describes the clinical features of one of them. He recognizes the difficulty in distinguishing a neuritis from certain forms of spinal disease, but he assumes that the presence of paræsthesiæ of the peripheral type, pains in and tenderness of the muscles to pressure, early absence of the reflexes and above all the fact of recovery, leave no doubt that a polyneuritis may be associated with or result from pernicious anæmia. Unfortunately he has not been able to confirm his diagnosis by a pathological examination.

The volume contains no noteworthy contribution to our knowledge of the ætiology of the disease. The author points out that various agents, as infections, intoxications and cachectic states, may produce both anæmia and changes in the nervous system, and emphasizes that in two of the three cases in which he was able to obtain autopsies there were neoplasms of the gastro-intestinal tract. He tends to the view that both the blood and the nervous changes are due to the same pathological agent.

Etudes neurologiques. Deuxième Série. Par GEORGES GUILLAIN. Pp. 360. Paris: Masson et Cie. 1925. Price 26 francs.

Professor Guillain's first series of neurological studies appeared in 1922.

As that, the present volume contains only articles and addresses already published in various medical journals, usually in collaboration with a colleague or assistant. Their collection in book form will be welcomed by those to whom the services of a good medical library are not available, and by those who

desire to study the trends of French neurology as represented by the work of the neurological clinic at the Salpêtrière. Some of the articles, it is true, are only sketchy or casual contributions to a society, but many have a permanent value that justifies their inclusion. They are grouped under various headings according to the subjects with which they mainly deal, the chief of which are nervous symptomatology; the pathology of the brain; spinal pathology; disseminated sclerosis and encephalitis lethargica.

It is a pity that paper of a better quality was not chosen for the publication.

J. Hughlings Jackson: Eine Studie über Krämpfe. Uebersetzt und eingeleitet von OTTO SITTIG. S. 149. Berlin: S. Karger. 1925. Price 2.20 marks.

In this volume Sittig has translated into German Hughlings Jackson's well-known article, "A Study of Convulsions." The complete English text is also included, the original and the German translation being printed on opposite pages, an arrangement which will make the book particularly useful to those not familiar with our language. The translation has been excellently done and seems to express accurately and clearly Jackson's whole meaning, a task which cannot have been, in many instances, easy. The reprinting of the original text is also welcome as it will enable English readers to obtain this extremely valuable contribution to neurology, which was first published in an obscure and now defunct journal and has been long out of print. It also makes us realize the desirability of reprinting and making more easily available to students others of Jackson's more important papers, and the debt we owe to Dr. Taylor who recently collected certain of his scattered articles into a volume.

Dr. Sittig also gives a short review of Jackson's life and activities, which is evidently based on Dr. James Taylor's introduction to "Neurological Fragments," and an analysis of his methods and of the nature of his special services to neurology.

A Textbook of Experimental Psychology. By C. S. MYERS and F. C. BARTLETT. Part II: Laboratory Exercises. Third Edition. Pp. 121. Cambridge: University Press. 1925. Price 7s.

The third edition of Myers' well-known textbook also bears the name of his successor, Mr. F. C. Bartlett, on the title-page.

Considerable variations, as compared with the second edition which appeared fourteen years ago, will be found chiefly in the form of new exercises devised for the study of mental functions. These add to the value of the book and will serve to interest the student in the more advanced attitudes of psychology. The descriptions of, and directions for, the experiments are still distinguished by the lucidity that made the earlier editions of the book so popular.

Ueber Hysterie. Von ERNST KRETSCHMER. S. 115. Leipzig: G. Thieme. 1923. Price 2.40 marks.

Kretschmer is already well known to students of psychology, and especially to neurologists and psychiatrists who are interested in its practical application, by his book on Medical Psychology.

The book under review, which deals with the nature of hysteria and the mode of origin of its various states and symptoms, is another noteworthy contribution. The views expressed and developed in it are based on accepted physiological and psychological principles; very rarely does the reader find an assumption made merely because it fits into his arguments, or, as is so common in treatises on this or similar subjects, a hypothesis or the statement of a creed put forward as an argument.

The first part of the book deals with the instincts and their relations to hysteria; in the second part, which is titled "The Psychophysical Dynamics of Hysteria," he discusses hysterical fixation and demonstrates its relation to simpler physiological and pathological habit formations, voluntary augmentation of the reflexes, the will factor in hysteria and certain conversion phenomena. The chapter in which the part played by the will in the pathogenesis of hysterical states is discussed is particularly useful and enlightening.

L'activité psychique: Les réactions centrales dans les phénomènes cérébraux. Par EDME TASSY. Pp. 126. Paris: F. Alcan. 1925. Price 9 francs.

The pretentious aim of this book is to point out the necessity of studying psychological phenomena from another angle in order to determine the basis of psychical activity, and to make it possible to integrate more completely the various components of the mind. The most important steps are to discover the origin and nature of the more elementary reactions and of immediate states which are not directly recognizable and not subject to experimentation. It is, according to him, necessary to establish the problems of psychology in such a way that they are always attached to a neurological or physiological basis. His views are essentially materialistic, but his book will be found interesting and instructive by all its readers no matter what their own predilections may be.

Le mystère psychique. Par G. DANVILLE. Pp. 160. Paris: F. Alcan. Price 9 francs.

Spiritualism and its various modifications, including telepathy, communication of thought, materialization and other allied phenomena, have become remarkably popular in France during the last few decades. The aim of the author of this small book is to examine objectively and impartially the alleged facts on which belief in supernatural agencies is based, and to review critically the tenets of the Spiritualists, especially from the psychological point of view.

He comes to the conclusion that the phenomena ascribed to spiritual agencies are, as has been proven in many instances, fraudulent, or due to voluntary or involuntary errors of observation or interpretation, or finally simple coincidences. Even the most ardent spiritualists admit that some of the most striking manifestations attributed to supernatural influences have been proved to be due to fraud, and he complains quite fairly that spiritualists provide no definition nor describe any positive features characteristic of what they regard as genuine, that can enable us to distinguish these from ordinary common deceptions. The credulous are those in whose psychological make-up sentimental logic predominates over rational logic.

Migraine and other Common Neuroses: A Psychological Study. By F. G. CROOKSHANK. Pp. 101. London: Kegan Paul, Trench, Trübner and Co., Ltd. 1925. Price 2s. 6d.

This is the first of a proposed series of monographs to be issued under the auspices of the journal *Psyche*. Although the two lectures which compose it were originally published in a medical journal the impression the book makes on the reader is that it is directed to the lay public as much as to the medical profession.

The first chapter, on the psychological interest in the common neuroses, contains nothing new, in fact the matter has been repeatedly put, and often more happily, in separate articles and similar volumes.

An unfortunate tendency to exaggerate often spoils the presentation of the author's views, and the use of such phrases as "the supremacy of mind over matter," and a sneer at "the pride of modern scientific research," tends to rob them of some of the sympathy the reader might give them if more reasonably put.

The second chapter deals with "Migraine and its Allies," especially trigeminal neuralgia. In sufferers with these conditions, it is asserted, an organ-inferiority is generally obvious, but the onset of a paroxysm is always associated with suppressed rage and humiliation. Further, according to the author, "the sex problem runs like a scarlet thread throughout."

Les maladies des glandes endocrines. Par KNUD H. KRABBE. Pp. 92. Paris: Librairie Le François. 1925.

This is a translation into French of a part of a Scandinavian textbook of medicine, with additional notes which did not appear in the Danish edition of 1922.

The effects of abnormal secretory function of the thyroid, pituitary, adrenal and sex glands are clearly described, the symptoms and diagnosis being fully dealt with. No new facts are brought forward, and the book is not for the expert; but the post-graduate student will find here a clearly written and adequate survey of the subject.

Essentials of Psychiatry. By GEORGE W. HENRY. Pp. 199. London: Baillière, Tindall and Cox. 1925. Price 13s. 9d.

This is an elementary text-book which may prove useful to the junior students or to anyone interested in the broad details of mental diseases. It is simply and clearly written, but despite its size and the number of pages it contains there are few descriptions sufficiently complete to give a clear picture of any of the forms of psychiatric disorders described. It can, therefore, be regarded only as an introduction to the subject. The first two chapters on the evolution of personality and the modes in which personality may fail to meet the stresses of environment are admirable; that devoted to the principles of treatment is also good, though it scarcely suggests the intimate contact with patients that the author has obviously enjoyed. It is, for instance, not easy for the student to see how the author employs psycho-analysis, to which he devotes some pages. There is also a chapter on psychiatric nursing, and another on special precautions in the case of psychiatric patients and the treatment of emergencies.

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